A DISCRETE DATA MODEL FOR THE HYDROLOGIC BASIN

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CERTIFICATE

This is to certify that the thesis entitled "A Discrete Data Model For the Hydrologic Basin" by Abhai Krishna Sharma is a record of work carried out under my supervision and has not been submitted elsewhere for a degree.

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Abhai Krishna Sharma

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NOTATION

Δt = time interval;

τ = dummy variable;

$a_i(Q, r, t)$ = integral coefficient of the system equation;

$b_j(Q, r, t)$ = differential coefficient of the system equation;

D = differential operator d/dt;

DSRO = direct surface runoff;

$\{f\}$ = detected input vector;

$\{G\}$ =$(g_1, g_2 \text{ --------- } g_n)$ i.e. the vector of coefficients defining linear system;

$\{h\}$ =$(h_1, h_2 \text{ -------- } h_n)$ i.e. differential coefficients of the direct system;

$[H]$ = system transfer functions of the differential components of the direct system;

$[H_o]$ = $\frac{1}{h_1}$ $[H]$ = standardised forms of $[T]$;

i = 1, 2, --------- m ;

i(t) = effective rainfall intensity;

$\bar{i}(n)$ = average effective rainfall;

$[I]$ = is the identity matrix;

IUH = instantaneous unit hydrograph;

j = 1, 2, --------- n;

L = limit of the discrete convolution integral (3.1)

m = $t/\Delta t$ = discrete time variable;

m = order of the derivative of r;

NOTATION (Contd.)

M	= number of precipitation values;
$M(D)$	= polynomial of D as numerator;
n	= order of the derivative of Q;
n	= order of model;
N	= number of DSRO Values;
$N(D)$	= polynomial of D as denominator;
$\{P\}$	= precipitation vector;
$\{Q\}$	= DSRO Vector;
$\{\bar{Q}\}$	= Vector of average DSRO;
$Q(t)$	= direct surface runoff;
$Q(m)$	= direct surface runoff;
$\{r\}$	= input vector;
t	= time of which DSRO is evaluated;
$\{t\}$	= $(t_1, t_2, \text{---------} t_n)$ integral coefficient vector of the direct system;
T	= translation time;
$[T]$	= system transfer functions of the integral components of the direct system
$[T_o]$	= $\frac{1}{t_1}[T]$ = standarised form of $[T]$;
$u(t)$	= IUH of the basin;
$[U]$	= system transfer matrix;
$[U_o]$	= $\frac{1}{u_1}[U]$ standardised form of $[U]$

A DISCRETE DATA MODEL FOR THE HYDROLOGIC BASIN

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Chow and Kulandaiswamy have presented a linear differential equation for the basin system. A discrete linear model corresponding to the above has been analysed by Chaube. This study deals with the applicability of the above model on consideration of a large number of storms for any basin. The apparent abstraction during and after the storm have been identified. A physical process to explain the variations in the effective rainfall and abstraction has been suggested. A simple linear system model has been found to be a satisfactory representation of the basin.

CHAPTER 1

INTRODUCTION

1.1 General:

The study of the natural hydrology processes is very complex. The hydrologist must deal with whatever climatic and physical conditions nature provides with little chance to choose or specify the combinations of factors he will consider. He is harassed in his study of natural processes by additional influencing factors which he can not always eliminate, control, or measure. An apparent relation between certain factors may be misleading because extraneous or unmeasured variables obscure the fundamental principles involved. When the hydrologist resorts to small-scale experiments to get better control of the influencing variables, he encounters difficulty in extending his results over larger areas and from one region to another. This is because the natural processes vary in complex ways in response to changing environmental conditions. The quantitative conclusions of an analysis drawn from a distinct set of physical conditions within

a specific location are not readily transferable to another problem. There is credence in the statement that "every watershed is a law unto itself".

The foregoing serves to illustrate the general difficulties hydrologists encounter in treating and analysing hydrologic problems. Such processes as interception, infiltration, percolation through soil, evapotranspiration, surface runoff, streamflow etc. are all characterized by constant change and complex interrelations, which make analytic discription and prediction most difficult. Many problems of hydraulic design are related to infrequent extreme events such as floods. One of the objectives in hydrologic analysis is to learn somthing of the frequency of occurrence of these extreme events. Several methods have been proposed, developed and used for the evaluation of basin yield and mean annual flood.

1.1.1 Simulation Models (4):

There are two major approaches to simulation modelling. The first is to design a deterministic model whose response is equivalent to the physical system.

This may be either through a black-box model or through a series of equations which are equivalent to the actual internal physics of the system. Because the problem resolves itself to the determination of the physical parameters describing the system, the deterministic approach often is called parametric modelling. The second major approach to simulation is to determine the statistical parameters describing the responses of the system, and to use these statistics to generate a record which is statistically indistinguishable from the measured record. This is called stochastic simulation.

Each of the two approaches has certain advantages and limitations which have resulted in its use for simulation in particular types of problems. Parametric modelling usually requires input data with considerable detail in time, and it models transient responses well. Therefore, it is most widely used for short-term simulation or for actual prediction for water management purposes. Stochastic simulation on the other hand, is most widely used for predictions for time periods which average out the transient responses. Transients are difficult to model as statistical parameters are

used to describe the response. Therefore stochastic simulation usually is used for planning purposes to develop many "equally likely" long term traces of monthly streamflow or similar smoothly varying responses. As far as the choice between discrete and continuous model is concerned, it has been found that discrete models of the hydrologic system constitute significant alternatives to classical continuous models.

1.1.2 Kinds of Problems in Hydrology (12):

Problems associated with a hydrologic system are either direct (forward) or inverse. In the direct problem the system is known prior to characterization in terms of a mathematical equation. The objective is to determine the nature of the output for any specified class of input. Many problems in hydraulics are direct in kind.

In the inverse problem the objective is to build a model that best describes the given input-output pair(s). Because best implies a criterion of fit or measure that is not absolute, the resulting model is non-unique. Classes of inverse problems include control, indentification and estimation (15). Other

inverse problems include detection (6) and instrumention.

The control (design) problem, either deterministic or stochastic, involves design of a non-existent system that satisfies desirable social goals according to some performance index such as cost, benefit, safety, etc. The identification problem entails estimation of parameters for an unknown but already-existing system given incomplete information on the observed inputs and outputs as well as system. The estimation problem is one of finding past, present, and future states of a system in the presence of a known system. Dooge (6) defines detection as a problem of detecting an unknown input signal when the output and the system with laws governing it are known. In the instrumention problem it is desired to identify a system. The inputs and outputs observed in nature are not accurate. If desirable, one may wish to create a special kind of input whose response reveals most about the system; thus, one wishes to design an input signal that best suits our needs.

1.2 Objective:

The objective of this study is to test and validate the discrete data model for the hydrologic

basin formulated by Ramaseshan and Chaubey (20). The inputs of apparent effective rainfall and abstraction will be detected and the system model identified, perhaps by improving the model and testing the validity of a simple linear model for the basin.

1.3 Significanee of Study:

The conventional unit hydrograph analysis makes empirical seperation of effective rainfall by using either mathematical methods and/or conceptual models. It estimates the unit hydrograph or other linear or non-linear system parameters. Kulandaiswamy (2) and Rao indicate that the non-linearity is significant for small discharges in the rising portion of the hydrograph. Since the effect of arbitrary seperation of effective rainfall excess is also significant in the same region of the hydrograph it is possible that the error may be due to effective rainfall seperation rather than non-linearity of the basin.

Dooge (5) observed that the hydrologic basin is a heavily lumped system. The basin is relatively in-sensitive with respect to the transformation of effective

rainfall to direct surface runoff. Thus satisfactory prediction of output in the direct analysis cannot be used as the sole criteria for testing the particular method of analysis and model.

Kishi (13) has indicated the possibility of using transform techniques in the indentification of the system and in the elimination of error effects in system indentification. However it may be noted that his procedure involves only smoothing of the high frequency variability of the system and output which leads to a very smooth detected input.

Chaubey (1) has investigated the use of inverse analysis and a discrete data model for identifying the hydrologic basin. He has verified that the discrete data model might behave much better than other models for the basin.

The study is divided into four phases namely -

(1) To refine the discrete data model by considering translation times and the time distribution of effective rainfall.

(2) To estimate the data errors in runoff.

(3) To estimate the effective rainfall and abstraction during the various storms and,

(4) To verify whether a simple linear model is satisfactory.

In case the linear model is found to be satisfactory it will constitute a simple rational model for the basin and may lead to better understanding of the processes of abstraction and runoff.

1.4 Scope of Study:

In the first three phases of the study data from two basins will be used. They are

(1) North Creek Basin (Area = 21.6 sq.miles)

(2) Beech River Basin (Area = 15.9 sq. miles).

In the last phase only the data of the first basin are used because of limitations of time and computer facilities. It should be noted that it is not the purpose of the study to investigate the relationship between abstractions and precipitation characteristics.

1.5 Details of the Report:

The study is reported in the following sequence:

1. Chapter 2 is a brief review of the relevent literature. The various methods of system identification have also been discussed.

2. Chapter 3 discusses the discretization of convolution relation and system representation through IUH, differential and difference equations. The mathematical formulation of the discrete data model has been explained. Finally the physical process of rainfall-runoff has been discussed.

3. The verification of the quasilinear model has been presented in Chapter 4. Here the parameters of the basin, the data errors and characteristics of effective rainfall and abstraction have been discussed for two basins. An explanation of the physical process of apparent effective rainfall and abstraction has also been given.

4. The linear model developed on the basis of the quasilinear analysis has been dealt with for one basin. Finally some tentative conclusions are drawn.

In addition there are two appendixes, one dealing with the proof for the translation effect and the other is a listing of the relevant computer programmes.

CHAPTER 2

REVIEW OF LITERATURES

2.1 General:

Modelling is the process whereby the physical properties of a system are expressed in a mathematical form suited to further analysis. One should bear in mind, however, that a model is at best an approximation to physical reality. It is a mathematical idealization representing selected aspects of the system's behaviour relevant to the problem at hand.

Rainfall-runoff studies moved from the use of the approximate empirical formulae prior to 1920 to consideration of the transformation of the rainfall by physical processes to resultant runoff and streamflow after 1930. Surface routing was the first component to receive emphasis, with the development of the unit-graph concept. The unit-graph introduced linear response theory into hydrology. Evaporation and infiltration were considered "losses", hydrograph separation techniques were used to determine surface runoff, and

the unit-graph was used to route the surface runoff.

The modelling of the surface flow routing component developed from the unit-graph to the use of conceptual models, such as the application of the use of the linear storage concept of hydrologic flood routing to derive the unit-graph. Finally, a unified mathematical theory was developed which related the various seemingly desperate approaches, and demonstrated that each was a particular case of the general theory.

The integrated system modelling has been developed with the advent of electronic digital computers. Objective fitting methods have been applied to parameter estimation. Parametric models have been developed with two differing approaches. The first is a bulk parameter approach, in which the modelling of the response function of the system is attempted. This is typified by the use of an instantaneous unit hydrograph (IUH) in surface streamflow modelling. The second approach is through a distributed parameter model where the internal states of the system are often of primary concern.

Stochastic modelling is a relative new comer to the science of hydrology. The approach in stochastic modelling is to give a statistical description of the measured response of the system. From the statistical description a statistical model is constructed.

Representation of linear hydrologic system in terms of IUH allows the direct surface runoff (DSRO) to be determined for any effective rainfall pattern by means of the convolution integral. Problem associated with IUH is that it can not be determined in a closed form which is independent of the data used. Let $u(t)$ be the IUH of the basin. Then the output $Q(t)$ is given by the convolution integral of effective rainfall intensity $i(t)$ with $u(t)$ i.e.,

$$Q(t) = \int_0^{t_1} u(t-\tau)\, i(\tau)\, d\tau \tag{2.1}$$

where $t_1 = t$ for $t \leqslant t_e$ (the duration of effective rainfall)

$t_1 = te$ for $t \geqslant te$

and t is the time at which DSRO is evaluated.

2.2 System Identification:

2.2.1 Black-box Method:

In hydrology, methods of system identification have been applied to linear (non-linear) stationary (non-stationary) lumped systems and to non-linear distributed systems. The traditional method of unit hydrograph derivation by the method of synthetic division is illustrative of the problem; the derived unit hydrograph is unique only with respect to the input-output pair used in its derivation, the initial conditions existing at the time of occurrence, and the abstraction methods employed to derive the pair. During the past 10 years both transform and correlation methods have been applied to the identification of the optimum unit hydrograph for lumped models of the rainfall-runoff process. The transform methods include Laplace (3), Fourier (14) and Z (11) transforms, harmonic (17) and Laguerre (5) coefficients

. The correlation methods of identification include least squares (8) and time series analysis. In time series analysis, the classical Wiener - Hopf equations are invoked to derive an optimum linear

predictor. Above, the systems were assumed to be truely or almost truly linear and stationary.

All these methods are essentially black box in kind where u(t) is found from input and output alone without any attention to the components. Details about the above methods are given in references (3, 5, 8, 11, 14, 17).

2.2.2 Conceptual Modelling:

One of the draw backs of the above approaches is that IUH is to be characterized in terms of a number of ordinates. In order to consider the variations of IUH as a function of storm and basin characteristics, it is preferable to represent the IUH in terms of a few parameters.

In contrast to black-box methods, efforts has been exerted to develop conceptual models of the rainfall runoff process. These conceptual models characterize the IUH in terms of a few parameters. Treating the effective rainfall as inflow and DSRO as outflow and the drainage basin as a combination of

reservoirs and channels through which the inflow is routed, various conceptual models have been developed. Parameters of such synthetic models are estimated by the method of moments and method of least squares applied to actual rainfall-runoff data. Details about these models are given in references (2, 3, 7, 16, 18, 19 and 21). Chaubey (1) found the difference equation to be valid for developing a discrete data model for the hydrologic basin

CHAPTER 3

THE DISCRETE DATA MODEL

3.1 General:

A digital computer is used in hydrologic analysis and the data used are also discrete, viz., quantized rainfall data and sampled runoff data. Ochoa and Eagleson (9) describe and discuss discrete representation of the hydrologic basin and their solution through Wiener-Hopf equations. Mathematical modelling of a basin is extremely useful because (a) emphasis is on model formulation (and thus basic physics of the phenomenon) and not on the solutions, (b) the analyst is able to experiment with a variety of formulations, without constraining or freezing the approach too early, (c) one can check the model rigorously for consistency, ambiguity, closeness, etc., (d) one can attack via computer simulation experiments (rather than in the laboratory or field) complex, vague, or ill-defined problems, thus allowing theory to complement intuition, and (e) one has

control over the discrete formulation such that assumptions are more directly interpretable in terms of the physics of the phenomenon. Discrete models of the hydrologic systems constitute significant alternatives to classical continuous models particularly because of factors, c, d, and e.

Chow and Kulandaiswamy (2) have proposed a general differential equation for the hydrologic basin which can be considered as a generalisation of several earlier models. A discrete data model (1) based on the differential equation has already been presented. It is briefly reviewed and refined in the following section.

3.2 System Representation:

3.2.1 System Representation Through IUH:

The convolution integral (equation 2.1) can be written in discrete form as

$$Q(m) = \sum_{n=0}^{L} u(m-n)\, \bar{i}\,(n)\, \Delta t \qquad (3.1)$$

where t is the time at which DSRO is to be evaluated, Δt is the time interval, $m = t/\Delta t$ is the discrete

time variable, $\bar{i}$ (n) is the average effective rainfall intensity over the time interval $(n-\frac{1}{2})\Delta t$ to $(n+\frac{1}{2})\Delta t$, t_e is the duration of effective rainfall, $M = t_e/\Delta t$, and

$$L = m \quad \text{for} \quad m \leq M$$

$$= M \quad \text{for} \quad m \geq M$$

Let $r(n) = \bar{i}(n)\Delta t$. Then

$$Q(m) = \sum_{n=0}^{L} u(m-n)\, r(n) \tag{3.1a}$$

or

$$\{Q\} = [U]\{r\} \tag{3.2}$$

where $\{Q\}$ is the output vector $Q(1), Q(2) \ldots$, $\{r\}$ is the input vector $r(1), r(2) \ldots \ldots$ and $[U]$ is the system tra sfer matrix given by

$$[U] = \begin{bmatrix} u_1 & 0 & 0 & - - - - - - - - & & \\ u_2 & u_1 & 0 & 0 & - - - - - - & \\ u_3 & u_2 & u_1 & 0 & - - - - - - & \\ - - - & - - - & - - - & - - - & - - - & \\ - - - & - - - & - - - & - - - & - - - & \\ u_n & u_{n-1} & u_{n-2} & - - - - & u_2 & u_1 \end{bmatrix} \tag{3.3}$$

Let $[U_o] = \frac{1}{u_1} \left[U \right]$; i.e.

$$\left[U_o \right] = \begin{bmatrix} 1 & 0 & 0 & 0 & ------ & \\ \frac{u_2}{u_1} & 1 & 0 & 0 & ------ & \\ \frac{u_3}{u_1} & \frac{u_2}{u_1} & 1 & 0 & ------- & \\ --- & --- & --- & --- & --- & \\ --- & --- & --- & --- & --- & \\ \frac{u_n}{u_1} & \frac{u_{n-1}}{u_1} & ------ & & \frac{u_2}{u_1} & 1 \end{bmatrix} \tag{3.3a}$$

$\left[U_o \right]$ is the standardised form of $\left[U \right]$. Then

$$\left\{ Q \right\} = u_1 \left[U_o \right] \left\{ r \right\} \tag{3.4}$$

$\left[U \right]$ and $\left[U_o \right]$ are lower half Toeplitz matrices.
From equations 3.2 and 3.4,

$$\left\{ r \right\} = \left[U \right]^{-1} Q = \frac{1}{u_1} \left[U_o \right]^{-1} \left\{ Q \right\} \tag{3.5}$$

where $\left[U \right]^{-1}$ and $\left[U_o \right]^{-1}$ are also lower half Toeplitz matrices.

3.2.2 Differential Representation of the System:

A general representation of the basin system is the differential equation .

$$\left[1 + \sum_{j=1}^{n} b_j \, (Q, r, t) \; D^j \right] Q(t)$$

$$= \left[1 - \sum_{i=1}^{m} a_i \, (Q, r, t) \; D^i \right] r(t) \qquad (3.6)$$

where a_i and b_j are parameters of the system and D is the differential operator d/dt. If a_i and b_j are independent of t, the system is time invariant, and if they are independent of Q and r the system is linear. Hence the lumped linear time invariant system can be represented by the equation.

$$\left[1 + \sum_{j=1}^{n} b_j \; D^j \right] Q(t) = \left[1 - \sum_{i=1}^{m} a_i \; D^i \right] r(t) \qquad (3.7)$$

$$\text{So} \quad Q(t) = \frac{\left[1 - \sum_{i=1}^{m} a_i \; D^i \right]}{\left[1 + \sum_{j=1}^{n} b_j \; D^j \right]} \, r(t) \qquad (3.8)$$

$$= \frac{M(D)}{N(D)} \; r(t) \qquad (3.8a)$$

where $M(D)$ and $N(D)$ are polynomials of operator D. $M(D)$ represents a differential operation on $r(t)$ and $N(D)$ represents an integral operation.

3.2.3 System Representation Through Difference Equations:

For discrete data analysis, a difference equation is a more appropriate representation of the system than the differential equation. Using the backward differences the system considered earlier in equation 3.7 can be represented by the equation

$$t_1\, Q(k) + t_2\, Q(k-1) + ---- + t_{n+1}\, Q(k-n)$$

$$= h_1\, r(k) + h_2\, r\,(k-1) + ---- h_{m+1}\; r(k-m) \qquad (3.9)$$

Here the coefficients t_1, ---- t_{n+1} are related to the coefficients b_1, ----, b_n of the differential equation and the coefficients h_1, ------, h_{m+1} are related to the coefficients a_1, ---, a_m respectively. Though similar schemes can be developed

using central and forward differences, backward differences are indicated above as they are useful in forecasting. For an initially relaxed system Q(0), Q(-1), - - - , Q(-n+1) and r(0), r (-1), - - - - , r(-m + 1) are all zero. Hence the system can be represented by the matrix equation.

$$\left[T \right] \left\{ Q \right\} = \left[H \right] \left\{ r \right\} \tag{3.10}$$

where $\left[T \right]$ and $\left[H \right]$ are lower half Toeplitz matrices with

$$\left[T \right] = \begin{bmatrix} t_1 & 0 & 0 & 0 & - - - - - - - - \\ t_2 & t_1 & 0 & 0 & 0 & - - - - - - \\ t_3 & t_2 & t_1 & 0 & 0 & - - - - - - \\ - - - - - - - - - - - - - - - - - - \\ - - - - - - - - - - - - - - - - - - \\ t_{n+1} & t_n & - - - - - & t_1 & 0 & 0 \\ 0 & t_{n+1} & - - - - - - - & t_1 & 0 & - - - \\ - - - - - - - - - - - - - - - - - - \\ - - - - - - - - - - - - - - - - - - \\ - - - - - - - - - & t_{n+1} & t_n & - - - - - - - & t_2 & t_1 \end{bmatrix}$$

and $\left[H\right]$ is similar to $\left[T\right]$ but with only (m+1) elements.

Hence from eqn. 3.10.

$$\left\{Q\right\} = \left[T\right]^{-1} \left[H\right] \left\{r\right\}$$

$$\text{and } \left\{r\right\} = \left[H\right]^{-1} \left[T\right] \left\{Q\right\} \tag{3.11}$$

Comparing these with equation 3.2 and 3.5.

$$\left[U\right] = \left[T\right]^{-1} \left[H\right]$$

$$\text{and } \left[U\right]^{-1} = \left[H\right]^{-1} \left[T\right] \tag{3.12}$$

Hence in analogy with terms M(D) and N(D) of the differential equation, $\left[T\right]$ and $\left[H\right]$ may be referred to as the system transfer functions of the integral and differential components of the direct system respectively. Conversely $\left[T\right]^{-1}$ and $\left[H\right]^{-1}$ will respectively be the system transfer functions of the differential and integral components of the inverse system.

Let $\left[T_o\right]$ and $\left[H_o\right]$ be the standardised forms of $\left[T\right]$ and $\left[H\right]$ respectively. Then

$$u_1 = h_1/t_1 \quad \text{and}$$

$$\left[U_o\right] = \left[T_o\right]^{-1} \left[H_o\right]$$

$$\left[U_o\right]^{-1} = \left[H_o\right]^{-1} \left[T_o\right] \qquad (3.13)$$

3.3 Mathematical Modelling of the Basin (20):

Consider the basin system represented by equation 3.10 and 3.11. As convolution is a commutative operation, the system can be alternatively represented by the equivalent equations

$$\left[Q\right]\left\{t\right\} = \left[R\right]\left\{h\right\} \qquad (3.14)$$

N = number of DSRO values.

where,

$$\left[Q\right] = \begin{bmatrix} Q(1) & 0 & - - - - - - - - - - \\ Q(2) & Q(1) & 0 & - - - - - \\ Q(3) & Q(2) & Q(1) & 0 - - - \\ - - - - - - - - - - - - - - \\ Q(N) & Q(N-1) & - - - - - & Q(1) \end{bmatrix}$$

and

$$
[R] = \begin{bmatrix}
R(1) & 0 & - - - - - - - - - - - & & & & \\
R(2) & R(1) & 0 & - - - - - - - - & & & \\
- - - - & - - - - & - - - - & - - - - & & & \\
- - - - & - - - - & - - - - & - - - - & & & \\
R(M) & R(M-1) & - - - - - - - & R(1) & 0 - - - - & & \\
0 & R(M) & - - - - - - - - - - & & R(1) & 0 - - - & \\
- - - - - - - - - & & R(M) & - - - - - - - - - & & - & R(1)
\end{bmatrix}
$$

Further

$$\{t\}^T = \{t_1, t_2, - - - - t_{n+1}, 0, 0, - - - , 0\} \quad 4$$

$$\{h\}^T = \{h_1, h_2, - - - - , h_{m+1}, 0, - - - , 0\}$$

If $\{r\}$ is known correctly or if the errors in $\{r\}$ are pure random, the $\{t\}$ and $\{h\}$ vectors can be estimated directly from the data by standard procedure in linear system analysis. Iterative procedure to refine the parameters as more and more data are available may also be used. However, only the precipitation data are known well in our case and hence the following sequential procedure is suggested. The values of m, M and n are generally small compared to N. Hence consider the last N-(n+M) rows of

equation 3.14.

$$\begin{bmatrix} Q(M+n+1) & Q(M+n) & - - - - - - - & Q(1) \\ - - - & - - - & - - - - & - - - \\ - - - & - - - & - - - - & - - - \\ Q(n) & Q(n-1) & - - - - - - & Q(1) \end{bmatrix} \begin{bmatrix} t_1 \\ t_2 \\ t_{n+1} \\ - \\ - \\ 0 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ - \\ - \\ - \\ - \\ 0 \end{bmatrix} \tag{3.14a}$$

Let $g_i = t_{i+1}/t_1$ for $i = 2, 3, - - -, n$

Then

$$\begin{bmatrix} Q(M+n+1) & Q(M+n) & - - - & Q(1) & 0 - - - 0 \\ Q(M+n+2) & Q(M+n+1) & - - - - - & Q(1) & 0 - - 0 \\ - - - & - - - & - - - & - - - & - - - \\ - - - & - - - & - - - & - - - & - - - \\ Q(N) & Q(N-1) & - - - - - - - & & (Q(1) \end{bmatrix} \begin{bmatrix} 1 \\ g_1 \\ g_2 \\ - \\ - \\ g_n \\ 0 \\ - \\ - \\ 0 \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ - \\ - \\ - \\ - \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

OR

$$\begin{bmatrix} Q(M+n) & Q(M+n-1) & ---- & Q(1) & 0 & ---- & 0 \\ - & - & - & - & - & - & - \\ - & - & - & - & - & - & - \\ - & - & - & - & - & - & - \\ Q(N-1) & Q(N-2) & --------- & & Q(1) & & \end{bmatrix} \begin{bmatrix} g_1 \\ g_2 \\ - \\ - \\ g_n \\ 0 \\ - \\ 0 \end{bmatrix} = -\begin{bmatrix} Q(M+n+1) \\ Q(M+n+2) \\ - \\ - \\ Q(N) \end{bmatrix}$$

(3.14b)

OR

$$\begin{bmatrix} Q(M+n) & Q(M+n-1) & ------ & Q(M+1) \\ Q(M+n+1) & Q(M+n) & ------ & Q(M+2) \\ - & - & - & - \\ - & - & - & - \\ Q(N-1) & Q(N-2) & -------- & Q(N-n) \end{bmatrix} \begin{Bmatrix} g_1 \\ g_2 \\ - \\ - \\ g_n \end{Bmatrix} = -\begin{bmatrix} Q(M+n+1) \\ Q(M+n+2) \\ - \\ - \\ - \\ Q(N) \end{bmatrix}$$

Let this be $[A] \times \{G\} = \{\bar{Q}\}$ (3.14c)

Then the least squares solution for $\{G\}$ is

$$\{G\} = \left[[A]^T [A]\right]^{-1} [A^T] \{\bar{Q}\} \qquad (3.15)$$

The discrete data representation of the basin system is a logical extension of Kulandaiswamy's basic differential equation for discrete data analysis. But it does not involve the approximate estimation of first and higher order derivatives of $Q(t)$ by a numerical procedure. The value of t_1 is estimated by the continuity equation.

The estimation of $\{h\}$ is more complicated. This is because the effective rainfall $r(t)$ is not known generally and is usually estimated by empirical seperation procedures from the data of rainfall $P(t)$. The following procedure eliminates the necessity for any such empirical procedure.

From equation 3.10 and 3.14

$$[H]\{r\} = [R]\{h\} = \{f\} \quad \text{(say)}$$

$$= [Q]\{t\} \qquad (3.16)$$

$$\text{So } \{r\} = [H]^{-1} \{f\}$$

$$= [H]^{-1} [Q] \{t\} \qquad (3.16a)$$

Knowing t_1 and $\{G\}$, $\{t\}$ and $\{f\}$ can be calculated.

Let $[H] = [I]$. Then $\{r\} = \{f\}$ (3.17)
where I is the identity matrix.
Consider the last (N-M-n) values of $\{f\}$

Since $\{P\}$ is zero for the last (N-M) values; for the last (N-M-n) values

$$\{r\} = \{f\} = \{0\} \quad (3.18)$$

The values of $\{r\}$ calculated from equations (3.16 or 3.16a) may differ slightly from zero indicating the effects of data error or modelling error. If in this range $\{f\}$ is nearly zero and the errors are negligible, the data and modelling errors in the falling limb may be ignored.

If, however, $\{f\}$ differs significantly from $\{0\}$ for the last (N-M-n) values, this indicates errors in data and/or model and so other methods like smoothing, filtering etc. may have to be adopted.

Let $\{f\}$ be not significantly different from $\{0\}$ for the last (N-M-n) values. Then consider the first M values of $\{f\}$. If they are respectively less than the

corresponding values of $\{P\}$ and larger than $\{0\}$, i.e.,

$$\{0\} \leqslant r \leqslant \{P\} \qquad (3.19)$$

for the first M values, then they are realistic inputs and the corresponding abstractions are given by $\{P-r\}$. For the example described in the next section a simple translation model (3.17) was found to be sufficient. It has been shown in the next section that the discrete data model is a convenient method for analysis, parameter estimation and detection of input in the case of hydrologic basins.

3.4 The Rainfall-Runoff Physical Process:

It is assumed that $\{0\} \leqslant \{r\} \leqslant \{P\}$. The assumption that $\{r\}$ is non-negative is in agreement with conventional practice. Let $\{r\} = \{P\} - \{L\}$, where L is the vector of abstractions. The physical process of this phenomenon has been depicted in Fig. 1.

The values of $\{r\}$ gives the detected effective rainfall. The mass curve of $\{r\}$ should be below the mass curve of $\{P\}$ and above the mass curve of $\{q\}$.

Chaube (1) considers only storage elements. It is possible that the basin has also a constant translation effect. In such a case, i.e., a IUH with translation time T will result in a detected effective rainfall which is nothing but the earlier one but shifted back by time T (vide Appendix I). It is referred to as the apparent effective rainfall and is indicated along with the detected effective rainfall in the figure 1.

Abstraction takes place during the storm. The rate of abstraction is higher during the storm which has been indicated by the curve AB. There is water in storage in the basin and in the channel after the end of the storm and so there is abstraction even though there is no precipitation. The rising curve BC indicates this feature of the process. It will generally be seen that the total effective rainfall during a storm is larger than the total direct surface runoff and the difference is abstracted after the end of the storm. Hence it is possible to have and reasonable to expect a negative effective rainfall when the rate of rainfall is low and also immediately after the storm. It should however be noted that the corresponding abstraction rates are realistic for the basin under consideration.

Presumably the bank storage starts replenishing the effective rainfall, i.e. at point C. It should be noted that point C should be beyond peak stage. This continues upto a stage D showing a fall in the curve along CD. Once again the net rate of abstraction is positive and it continues upto E with an increase in abstraction from basin storage. After E once again interflow might occur and reduce the rate of abstraction which is signified by the fall in the curve along EF, After F the losses become negligible and the curve becomes parallel to the time axis. Corresponding variations in the effective rainfall curves may also be noted.

It should however be noted that certain phases of the rainfall-runoff process described above might not be present in some basins as each has its own characteristics.

CHAPTER 4

VERIFICATION OF QUASILINEAR MODEL

4.1 General:

Chaubey (1) has verified the model with reference to number of individual storm. His study has indicated that the model gives quite satisfactory results. In this study the applicability of the model to hydrologic basins on the basis of a number of storm-flood events is investigated. The data for two basins, viz., North Creek Basin, NCB (seven storms) and Beech River Basin, BRB (eight storms) were available and were found to be satisfactory from consideration of reliability of data, etc. They were used in this study.

4.2 Results:

The phases of the study include (1) to estimate the effective rainfall and abstractions during the storms, (2) to refine the discrete data model by considering translation times and the time distribution of effective rainfall and (3) to estimate the data errors

in runoff.

The model was studied from first order to tenth order. After the analysis of the results obtained from them, it was found that the second order model gives satisfactory results for all storms of both basins.

The results for the second order model are presented in the Tables 1 to 7 for NCB and 8 to 15 for BRB. Tables 1 to 7 include the given values of time, precipitation and direct surface runoff and the calculated values of apparent effective rainfall and abstraction from quasi-linear and linear models along with the fitted values for NCB. Tables 8 to 15 contain all the above mentioned values for BRB except for the linear model values. The plots of cumulative rainfall-runoff characteristics are presented for all the storms of both the basins and the rainfall-runoff intensity characteristics for only NCB have been presented. The factors taken into consideration in the plotting of smooth apparent effective rainfall and abstraction curves have been described in section 3.2.3. The symbols for the different rainfall-runoff characteristics are given in Fig. 2.

4.3 Discussion of Results:

4.3.1 Parameters:

The parameters g_1 and g_2 for the second order model with the translation times T for each of the storms of both the basins are given in Tables 16 and 17. It is seen that the values of g_1 and g_2 for storms 2 and 4 of NCB and storm 8 of BRB are significantly different from those of other storms of the respective basins. It may be necessary to investigate the reasons for such discrepency.

4.3.2 Translation Times:

It is found that the translation time for different storms of the basins varies within small limits. Most of the storms of NCB have a translation time of one hour except for 2 and 4 which has no translation time and storm number 1 has a value of $1\frac{1}{2}$ hours. Most of the storms of Beech River Basin have a translation time of four hours except for storm number 5 and 6 with 3 hours translation time.

4.3.3 Data Error in Falling Limb of Hydrograph:

The net abstraction rate after the end of precipitation was much smaller than during intensive precipitation. Thus for example in storm 1 of basin 1 (Table 1) abstraction during the storm is of the order of 1.20 in/hr and it becomes 0.10 in/hr after the storm. This seems reasonable. The data errors in q after important inflow and abstraction components receded are of the order of 0.01 inch or less. Since this is less than the least count (0.01 inch) of the rainguage, they may be considered negligible in all the storms of both the basins. It is realised that the method of least squares for estimating g_1 and g_2 is to be applied only where the data errors are negligible. It is possible to calculate once again the value of g_1 and g_2 over this region. However, the results were considered satisfactory and because of lack of time such refinements were not incorporated in this study.

4.3.4 Data Error in Rising Limb of the Hydrograp:

From the mass curves of apparent effective rainfall and apparent abstractions data errors in the discharge data in the rising limb of the hydrograph are observed.

For example in the case of storm 1, basin 1 (Table 1 Fig. 2) the values of abstraction and effective rainfall at 3.5 hours seen to be not in confirmity with the trend of the processes around 3.5 hours and smooth curve indicated seems to be more reasonable. It should be noted that by 4 or 4.5 hours the calculated

and fitted mass curves are in agreement. Such an error may be due to an over estimation of discharge at 3.5 hours. While the magnitude of the actual estimated error can be calculated by comparing the observed discharge with that obtained by the convolution of effective rainfall by IUH, such a procedure was not attempted in this study. Strom 5 basin 1 (Table 5; Fig. 6) also indicates such changes in the mass curves of apparent effective rainfall and apparent abstractions around 1.5 hours. However this may be due to the sudden decrease in precipitation. Similar errors are also observed around 2 to 3 hours in storm 3 of basin 1 and around 5th hour in storm 6 of basin 1. In the case of storms 2 in basin 2, storms 2 and 7 have two well defined bursts seperated by a few hours and the results of detection seem to be erraneous. They need further investigation.

4.3.5 Characteristics of Effective Rainfall and Abstraction

During the major portion of each storm in both basins, the mass curve of apparent effective rainfall and apparent abstraction are continuously rising.

Smoothening is required in case of storm number 1 of NCB due to negative abstraction occuring at 3.5 hours. In case of BRB, storms 2 and 7 have two well defined bursts seperated by a few hours and the mass curve for abstraction has a decreasing tendency which indicates the effect of bank flow. The intensity of effective rainfall is always less than the precipitation values till nearly the end of the storm. In few cases where the intensity of precipitation is very small, the effective rainfall values exceed precipitation.

The bank storage continues to replenish the effective rainfall for a few hours after the end of the storm. Storm number 4 (Fig. 8) of NCB and number 8 (Fig. 23) of BRB show a different tendency. The mass curve for abstraction for quasilinear system model shows a continuously increasing tendency till the end of the storm and thereafter a constant value. But in all other storms of the two basins the mass curve for abstraction has a falling limb for a few hours following the peak until the end of the flood. The linear model (Chapter 5) for NCB on the storm 4 (Fig.8) of NCB on the other hand confirms to the general

behaviour of all storms.

The mass curve of abstraction again rises in case of NCB indicating that the net rate of abstraction is positive. This continues for a few hours after which the rate of abstraction once again decreases indicating the possibility of interflow taking place. This continues for a few hours and then the losses become negligible and the curves becomes a straight line. In case of storm numbers of 2 (Fig. 4) and 4 (Fig. 8) of basin 1 the interflow component is absent. In case of BRB the losses becomes negligible only a few hours after the end of the storm. Hence interflow does not seem to occur in this case.

4.4 Conclusion:

Thus detection gives an insight into the basic hydrologic process of rainfall-runoff including the identification of components like abstraction, bankflow and interflow. Linear modelling may hence be satisfactory for representation of the hydrologic basin and nonlinear models, if any, are to be used with detection as a criterion in the modelling process.

CHAPTER V

VERIFICATION OF LINEAR MODEL

5.1 General:

Quantitative estimates require modelling. The more closely the model approximates the system modelled, the more accurate is the prediction obtained by using the model. At the same time, accuracy of prediction usually is purchased at the price of complicating the model which makes a model more difficult to use. In the case of a quasilinear model the parameters are assumed to be specified functions of quantified storm characteristics. The parameters of a linear model on the other hand are constants and so do not require any such empirical functional relationships. Keeping this in view the North Creek Basin is represented by a linear model.

A second order model was selected to represent the basin onthe basis of the quasilinear analysis (Chapter 4). The values of the two parameters g_1 and g_2 for each storm is given in Table 16. The

average values of the two parameters for all storms (except 2 and 4, which were inconsistent with the rest) were calculated and used as the parameters of a second order linear system model for the basin. A better method of finding the most appropriate values of g_1 and g_2 would have been to use the method of weighted least squares on all storms. But as the values of g_1 and g_2 had already been estimated from the quasilinear analysis, taking the mean was considered to be quite satisfactory.

5.2 Discussion of Results:

The values of apparent effective rainfall and abstraction via linear model of all the storms of the basin are given in Tables 1 to 7. The plots have also been indicated in Figures 2 to 15.

The apparent effective rainfall and abstraction were calculated by using the fixed parameters for a second order model and the procedure explained earlier in section 3.3. It has been found that there is not much of difference from the values calculated by the quasilinear model. The trend of the mass curves are

the same except for storms number 2 and 4. In these storms the curves now also shows the possibility of the occurrence of recharge from bank storage and interflow, thus agrees with the general behaviour of the storms. The difference in case of different storms is only in magnitude and not in the behaviour of the basin.

5.3 Conclusion:

Hence it is found that the linear model can be expected to be a good and satisfactory representation of the basin. The order of the model and parameters of the system can be estimated by the procedure developed in this study.

CHAPTER 6

SUMMARY, CONCLUSIONS AND SUGGESTIONS FOR FUTURE WORK

6.1 Summary of the Study:

Chow and Kulandaiswamy have presented a linear differential equation for the basin system. A discrete linear model corresponding to the above has been analysed by Chaube. This study deals with the applicability of the above model on consideration of a large number of storms for North Creek Basin and Beech River Basin. The apparent abstraction during and after the storm have been identified. A physical process to explain the variations in the effective rainfall and abstraction has been suggested. A simple linear system model has been found to be a satisfactory representation of the basin.

6.2 Conclusions:

The discrete data representation of the basin is found to be valid tool in physical modelling of the rainfall-runoff process. A second order model with translation time is generally found to be satisfactory. A linear

model with constant parameters is a simple and realistic representation of the basin system. It also helps in understanding of the component process of effective rainfall and abstraction.

6.3 Suggestions For Future Work:

(1) Direct surface runoff has been used in this study and hence it may involve errors due to wrong base-flow separation. In order to eliminate such errors and to understand the base flow contributions better it seems desirable to use discharge hydrograph rather than DSRO hydrograph.

(2) The model is to be tested for a larger number of basins and the abstraction and effective rainfall components are to be studied in terms of physical process models (Infiltration models and correlation of infiltration or recharge as function of storm storage and basin characteristics.)

(3) The effective rainfall during the storm is to be related to storm precipitation data from a number of guaging station and so a multiple input modelling

may be necessary to explain variation of precipitation and abstractions over the various sub-basins.

(4) Detection may be used as a tool in realistic nonlinear modelling of the basin system.

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TABLE 1 : RAINFALL RUNOFF CHARACTERISTICS

BASIN 1 STORM 1

Time	Precipitation	Direct Surface Runoff	Apparent Effective Rainfall			Apparent Abstraction		
			Quasi-Linear Model	Fitted	Linear Model	Quasi-Linear Model	Fitted	Linear Model
in hour	in/hr	in/hr	in/hr			in/hr		
1	2	3	4	5	6	7	8	9
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.5	1.480	0.0	0.4271	0.4271	0.4105	1.053	1.0530	1.0700
1.0	2.880	0.0079	0.4096	0.4096	0.3990	2.480	2.4800	2.4810
1.5	0.840	0.0332	0.1013	0.1013	0.1103	0.739	0.7390	0.7300
2.0	1.200	0.0759	0.1205	0.1205	0.1274	1.080	1.0800	1.0726
2.5	0.780	0.1078	0.1899	0.1899	0.1928	0.590	0.5900	0.5872
3.0	0.760	0.1312	0.5388	0.5388	0.5265	0.221	0.2210	0.2335
3.5	0.700	0.1516	0.9006	0.363	0.8787	-0.201	0.3370	-0.1787
4.0	1.040	0.1915	0.0784	0.350	0.1044	0.962	0.690	0.9356
4.5	1.740	0.2664	0.0509	0.317	0.0717	1.689	1.423	1.6683
5.0	1.400	0.3070	0.3424	0.3424	0.3439	1.057	1.057	1.0561
5.5	0.300	0.3188	0.2993	0.2993	0.3027	0.001	0.001	0.0000
6.0	0.300	0.3286	0.3221	0.3221	0.3235	-0.022	-0.022	-0.0235
6.5	0.2100	0.3361	0.3601	0.3601	0.3594	-0.150	-0.150	-0.1494
7.0	0.2100	0.3394	0.1569	0.1569	0.1655	0.053	0.053	0.0445
7.5	0.0	0.3261	0.0192	0.0192	0.0304	-0.0190	-0.0190	-0.0304
8.0	0.0	0.3394	-0.0928	0.0330	-0.0821	0.093	-0.0330	-0.0821
8.5	0.0	0.3296	-0.0150	0.0500	-0.1435	0.150	-0.0500	0.1435
9.0	0.0	0.3201	-0.0529	0.0250	-0.0561	0.053	-0.0250	0.0561
9.5	0.0	0.2565	-0.0631	0.0000	-0.0682	0.062	0.0000	0.0682
10.0	0.0	0.1973	0.1624	0.0	0.1458	-0.162	0.0	-0.1458

Continued Table 1

1	2	3	4	5	6	7	8	9
10.5	0.0	0.1388	0.1809	0.0	0.1670	-0.181	0.0	-0.1670
11.0	0.0	0.0840	0.0662	0.0	0.0611	-0.066	0.0	-0.0611
11.5	0.0	0.5030	0.0162	0.0	0.0146	-0.016	0.0	-0.0146
12.0	0.0	0.0350	0.0435	0.0	0.0408	-0.044	0.0	-0.0408
12.5	0.0	0.0262	-0.0304	0.0	-0.0291	0.030	0.0	-0.0291
13.0	0.0	0.0193	0.0429	0.0	0.0402	-0.043	0.0	-0.0402
13.5	0.0	0.0160	-0.0016	0.0	-0.0016	0.001	0.0	0.0016
14.0	0.0	0.0106	-0.0029	0.0	-0.0029	0.003	0.0	0.0029
14.5	0.0	0.0089	0.0113	0.0	0.0106	0.011	0.0	-0.0106
15.0	0.0	0.0070	-0.0004	0.0	-0.0004	0.000	0.0	0.0004
15.5	0.0	0.0050	-0.0014	0.0	-0.0014	0.001	0.0	0.0014
16.0	0.0	0.0040	-0.0176	0.0	-0.0169	0.018	0.0	0.0169
16.5	0.0	0.0030	0.0000	0.0	0.0	0.000	0.0	0.0
17.0	0.0	0.0020	0.0	0.0	0.0	0.0	0.0	0.0

TABLE 2 : RAINFALL RUNOFF CHARACTERISTICS

BASIN 1 STORM 2

Time	Precipi-tation	Direct Surface Runoff	Apparent Effective Rainfall			Apparent Abstraction		
			Quasi-linear Model	Fitted	Linear Model	Quasi-linear Model	Fitted	Linear Model
in hours	in/hr	in/hr		in/hr			in/hr	
1	2	3	4	5	6	7	8	9
0	0.0	0.0	0.0	Same as Quasi-Linear Model	0.0	0.0	Same as Quasi-linear Model	0.0
0.5	0.5200	0.0	0.0		0.0	0.5200		0.5200
1.0	0.6200	0.0015	0.0099		0.0218	0.6100		0.5982
1.5	0.2000	0.0027	0.0073		0.0038	0.1927		0.1962
2.0	0.0200	0.0032	0.0043		-0.0021	0.0157		0.0221
2.5	0.0200	0.0081	0.0148		0.0695	0.0052		-0.0496
3.0	0.0800	0.0150	0.0466		0.0593	0.0344		0.0207
3.5	0.6400	0.0239	0.0639		0.0752	0.5761		0.5648
4.0	0.0800	0.0280	0.0383		-0.0059	0.0417		0.0859
4.5	0.1400	0.0320	0.0486		0.0451	0.0914		0.0949
5.0	0.0500	0.0354	0.0488		0.0414	0.0022		0.0086
5.5	0.0800	0.0400	0.0609		0.0684	0.0190		0.0116
6.0	0.01000	0.0439	0.0592		0.0507	-0.0492		-0.0407
6.5	0.0100	0.0473	0.0608		0.0544	-0.0508		-0.0444
7.0	0.0300	0.0504	0.0630		0.0585	-0.0330		-0.0285
7.5	0.0300	0.0462	0.0184		-0.0416	0.0116		0.0716
8.0	0.0	0.0377	-0.0037		-0.0349	0.0037		0.0349
8.5	0.0	0.0307	0.0038		0.0217	-0.0038		-0.0217
9.0	0.0	0.0242	-0.0021		0.0068	0.0021		-0.0068
9.5	0.0	0.0190	-0.0007		0.0142	0.0007		-0.0142
10.0	0.0	0.0154	0.0027		0.0191	-0.0027		-0.0191
10.5	0.0	0.0115	-0.0051		0.0050	0.0051		-0.0050

Continued Table 2

1	2	3	4	5	6	7	8	9
11.0	0.0	0.0090	0.0006	Same as Quasi-linear Model	0.0145	-0.0006	Same as Quasi-linear Model	-0.0145
11.5	0.0	0.0064	-0.0045		-0.0036	0.0045		0.0036
12.0	0.0	0.0050	0.0009		0.0123	-0.0009		-0.0123
12.5	0.0	0.0039	-0.0002		0.0031	0.0002		-0.0031
13.0	0.0	0.0031	0.0002		0.0034	-0.0002		-0.0034
13.5	0.0	0.0023	-0.0010		-0.0005	0.0010		0.0005
14.0	0.0	0.0016	-0.0011		0.0002	0.0011		-0.0002
14.5	0.0	0.0012	0.0000		0.0028	0.0		-0.0028
15.0	0.0	0.0010	0.0004		0.0023	-0.0004		-0.0023
15.5	0.0	0.0008	0.0000		0.0001	0.0000		-0.0001
16.0	0.0	0.0006	0.0002		0.0000	-0.0002		0.0000
16.5	0.0	0.0004	0.0004		-0.0003	-0.0004		0.0003
17.0	0.0	0.0000	0.0019		0.0034	-0.0019		-0.0034

TABLE 3 : RAINFALL RUNOFF CHARACTERISTICS

BASIN 1 STORM 3

Time	Precipi- tation	Direct Surface Runoff	Apparent Effective Rainfall			Apparent Abstraction		
			Quasi- linear Model	Fitted	Linear Model	Quasi- linear Model	Fitted	Linear Model
in hours	in/hr	in/hr	in/hr			in/hr		
1	2	3	4	5	6	7	8	9
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.5	0.7400	0.0	0.0	0.0	0.0	0.7400	0.7400	0.7400
1.0	0.6500	0.0	0.1705	0.1705	0.1011	0.4800	0.4800	0.5499
1.5	2.6200	0.0070	2.3720	2.3720	1.4160	0.2480	0.2480	1.2040
2.0	0.7800	0.1094	-0.1678	0.2380	0.0388	0.9478	0.5420	0.7412
2.5	0.4200	0.1754	0.5828	0.1500	0.4773	-0.1628	0.2700	-0.0573
3.0	0.1200	0.2420	-0.1238	0.1100	0.0858	0.2438	0.0100	0.0340
3.5	0.0	0.2773	-0.1115	0.0900	0.0787	0.1115	-0.0900	-0.0787
4.0	0.0	0.2880	0.1887	0.0700	0.2386	-0.1887	-0.0700	-0.2368
4.5	0.0	0.2920	0.0068	0.0500	0.1262	-0.0068	-0,0500	-0.1262
5.0	0.0	0.2833	0.4997	0.0	0.4033	-0.4997	0.0	-0.4033
5.5	0.0	0.2856	0.1997	0.0	0.2364	-0.1997	0.0	-0.2364
6.0	0.0	0.2838	-0.1041	0.0	0.0517	0.1041	0.0	-0.0517
6.5	0.0	0.2665	-0.4328	0.0	-0.1644	0.4328	0.0	0.1644
7.0	0.0	0.2247	-0.2332	0.0	-0.0854	0.2332	0.0	0.0854
7.5	0.0	0.1743	-0.5077	0.0	-0.2766	0.5077	0.0	0.2766
8.0	0.0	0.1082	0.3093	0.0	0.1667	-0.3093	0.0	-0.1667
8.5	0.0	0.0665	0.2788	0.0	0.1540	-0.2788	0.0	-0.1540
9.0	0.0	0.0437	0.1297	0.0	0.0737	-0.1297	0.0	-0.0737
9.5	0.0	0.0300	0.1166	0.0	0.0687	-0.1166	0.0	-0.0687
10.0	0.0	0.0232	-0.0342	0.0	-0.0171	0.0342	0.0	0.0171

Continued Table 3

1	2	3	4	5	6	7	8	9
10.5	0.0	0.0157	0.1026	0.0	0.0603	-0.1026	0.0	-0.0603
11.0	0.0	0.0136	-0.0232	0.0	-0.0101	0.0232	0.0	0.0101
11.5	0.0	0.0105	0.0139	0.0	0.0097	-0.0139	0.0	-0.0097
12.0	0.0	0.0083	-0.0243	0.0	-0.0130	0.0243	0.0	0.0130
12.5	0.0	0.0053	0.0483	0.0	0.0280	-0.0483	0.0	-0.0280
13.0	0.0	0.0048	0.0018	0.0	0.0026	-0.0018	0.0	-0.0026
13.5	0.0	0.0043	-0.0084	0.0	-0.0037	0.0084	0.0	0.0037
14.0	0.0	0.0034	-9.0068	0.0	-0.0035	0.0068	0.0	0.0035
14.5	0.0	0.0023	0.0006	0.0	0.0003	-0.0006	0.0	-0.0003
15.0	0.0	0.0014	-0.0015	0.0	-0.0011	0.0015	0.0	0.0011
15.5	0.0	0.0006	0.0007	0.0	-0.0000	-0.0007	0.0	0.0000
16.0	0.0	0.0000	0.0	0.0	0.0	0.0	0.0	0.0

TABLE 4 RAINFALL RUNOFF CHARACTERISTICS

BASIN 1 STORM 4

Time	precipitation	Direct Surface Runoff	Apparent Effective Rainfall			Apparent Abstraction		
			Quasi-linear Model	Fitted	Linear Model	Quasi-linear Model	Fitted	Linear Model
in hours	in/hr	in/hr	in/hr		in/hr		in/hr	
1	2	3	4	5	6	7	8	9
0	0.0	0.0	0.0		0.0	0.0		0.0
0.5	0.2600	0.0	0.0	Same as Quasi-linear Model	0.0	0.2600	Same as Quasi-linear Model	0.2600
1.0	0.1700	0.0	0.0004		0.0014	0.1696		0.1686
1.5	0.5700	0.0	0.0093		0.0307	0.5607		0.5400
2.0	0.7000	0.0001	0.2005		0.6639	0.0500		0.0361
2.5	0.1800	0.0023	0.0099		-0.3645	0.1700		0.5445
3.0	1.0800	0.0498	0.0705		0.0617	1.0095		1.0183
3.5	0.1200	0.0539	0.1053		0.1829	0.0147		-0.0629
4.0	0.2200	0.0573	0.1212		0.1504	0.0888		0.0700
4.5	0.2400	0.0684	0.1175		0.0415	0.1225		0.1985
5.0	0.2200	0.0818	0.0823		-0.0113	0.1377		0.2313
5.5	0.2000	0.0883	0.0593		0.0245	0.1407		0.1755
6.0	0.3300	0.0859	0.0559		0.0708	0.2741		0.2592
6.5	0.7400	0.0800	0.0811		0.1549	0.6589		0.5851
7.0	0.5700	0.0753	0.0866		0.0817	0.4834		0.4883
7.5	0.2600	0.0776	0.0567		-0.0218	0.2033		0.2818
8.0	0.0900	0.0795	0.0180		-0.0482	0.0720		0.1382
8.5	0.0400	0.0738	-0.0134		-0.0441	0.0534		0.0841
9.0	0.0400	0.0614	-0.0134		0.0382	0.0534		0.0018
9.5	0.0400	0.0455	0.0009		0.0620	0.0390		-0.0220
10.0	0.0	0.0340	-0.0012		0.0013	0.0012		-0.0013

Continued Table 4

1	2	3	4	5	6	7	8	9
10.5	0.0	0.0280	-0.0030	Same as Quasi-linear Model	0.0097	0.0030	Same as Quasi-linear Model	-0.0097
11.0	0.0	0.0220	-0.0015		0.0149	0.0015		-0.0149
11.5	0.0	0.0170	0.0008		0.0146	-0.0008		-0.0146
12.0	0.0	0.0134	0.0031		0.0132	-0.0031		-0.0132
12.5	0.0	0.0110	0.0001		-0.0044	-0.0001		0.0044
13.0	0.0	0.0095	0.0032		0.0173	-0.0032		-0.0173
13.5	0.0	0.0075	0.0009		-0.0049	-0.0009		0.0049
14.0	0.0	0.0068	0.0025		0.0112	-0.0025		-0.0112
14.5	0.0	0.0055	-0.0016		-0.0116	0.0016		0.0116
15.0	0.0	0.0050	0.0000		0.0098	0.0000		-0.0098
15.5	0.0	0.0035	0.0012		0.0045	-0.0012		-0.0045
16.0	0.0	0.0029	0.0011		0.0013	-0.0011		-0.0013
16.5	0.0	0.0026	0.0008		0.0009	-0.0008		-0.0009
17.0	0.0	0.0023	0.0001		-0.0008	-0.0001		0.0008
17.5	0.0	0.0020	0.0005		0.0027	-0.0005		-0.0027
18.0	0.0	0.0016	0.0004		0.0005	-0.0004		-0.0005
18.5	0.0	0.0014	0.0002		0.0003	-0.0002		-0.0003
19.0	0.0	0.0012	0.0000		0.0001	0.0000		-0.0001
19.5	0.0	0.0010	0.0002		0.0013	-0.0002		-0.0013
20.0	0.0	0.0008	0.0002		0.0002	-0.0002		-0.0002
20.5	0.0	0.0007	0.0001		0.0001	-0.0001		-0.0001
21.0	0.0	0.0006	-0.0004		-0.0014	0.0004		0.0014
21.5	0.0	0.0005	-0.0002		0.0008	0.0002		-0.0008
22.0	0.0	0.0003	-0.0007		-0.0017	0.0007		0.0017
22.5	0.0	0.0002	0.0		0.0	0.0		0.0

TABLE 5 : RAINFALL RUNOFF CHARACTERISTICS

BASIN 1 STORM 5

Time	Precipitation	Direct Surface Runoff	Apparent Effective Rainfall			Apparent Abstraction		
			Quasi-linear Model	Fitted	Linear Model	Quasi-linear Model	Fitted	Linear Model
in hours	in/hr	in/hr	in/hr			in/hr		
1	2	3	4	5	6	7	8	9
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.5	0.3200	0.0	0.0328	0.0328	0.0188	0.2872	0.2872	0.3012
1.0	0.7600	0.0013	0.2960	0.0672	0.1733	0.4640	0.6928	0.5867
1.5	0.1600	0.0141	-0.1938	0.0352	-0.0720	0.3538	0.1248	0.2320
2.0	0.1000	0.0170	0.0278	0.0278	0.0241	0.0835	0.0835	0.0278
2.5	0.1200	0.0195	0.0202	0.0202	0.0306	0.0922	0.0922	0.0900
3.0	0.1800	0.0220	0.1145	0.1145	0.0273	0.1600	0.1600	0.1527
3.5	0.2400	0.0241	0.2141	0.2141	0.0811	0.1225	0.1225	0.1589
4.0	0.0	0.0295	0.2227	0.1950	0.1489	-0.2227	-0.2141	-0.1489
4:5	0.0	0.0415	-0.0645	0.0000	0.1758	0.0645	-0.1950	-0.1758
5.0	0.0	0.0591	-0.0551	0.0000	0.0333	0.0551	0.0	-0.0333
5.5	0.0	0.0695	-0.1071	0.0	0.0247	0.1071	0.0	-0.0247
6.0	0.0	0.0736	-0.0779	0.0	-0.0194	0.0779	0.0	0.0194
6.5	0.0	0.0700	-0.0568	0.0	-0.0240	0.0568	0.0	0.0240
7.0	0.0	0.0610	0.0581	0.0	-0.0296	-0.0581	0.0	0.0296
7.5	0.0	0.0485	0.0667	0.0	0.0218	-0.0667	0.0	-0.0218
8.0	0.0	0.0380	0.0290	0.0	0.0274	-0.0290	0.0	-0.0274
8.5	0.0	0.0300	0.0506	0.0	0.0088	-0.0506	0.0	-0.0088
9.0	0.0	0.2230	0.0597	0.0	0.0208	-0.0597	0.0	-0.0208
9.5	0.0	0.0180	-0.0011	0.0	0.0290	0.0011	0.0	-0.0290
10.0	0.0	0.0153	0.0126	0.0	-0.0010	-0.0126	0.0	0.0010
10.5	0.0	0.0123	0.0113	0.0	0.0047	-0.0112	0.0	-0.0047

Continued Table 5

1	2	3	4	5	6	7	8	9
11.0	0.0	0.0097	0.0179	0.0	0.0039	-0.0179	0.0	-0.0039
11.5	0.0	0.0075	0.0011	0.0	0.0078	-0.0011	0.0	-0.0078
12.0	0.0	0.0060	-0.0131	0.0	-0.0007	0.0131	0.0	0.0007
12.5	0.0	0.0045	0.0338	0.0	-0.0094	-0.0338	0.0	0.0094
13.0	0.0	0.0025	0.0003	0.0	0.0153	-0.0003	0.0	-0.0153
13,5	0.0	0.0020	0.0074	0.0	-0.0002	-0.0074	0.0	0.0002
14.0	0.0	0.0015	-0.0094	0.0	0.0036	0.0094	0.0	-0.0036
14.5	0.0	0.0013	0.0083	0.0	-0.0054	-0.0083	0.0	0.0054
15.0	0.0	0.0007	-0.0001	0.0	0.0038	0.0001	0.0	-0.0038
15.5	0.0	0.0005	0.0002	0.0	-0.0004	-0.0022	0.0	0.0004
16.0	0.0	0.0003	-0.0013	0.0	0.0008	-0.0013	0.0	-0.0008
16.5	0.0	0.0002	0.0000	0.0	-0.0002	0.00000	0.0	0.0002
17.0	0.0	0.0001	0.0000	0.0	-0.0003	0.00000	0.0	0.0003

TABLE 6 RAINFALL RUNOFF CHARACTERISTICS

BASIN 1 STORM 6

Time	Precipitation	Direct Surface Runoff	Apparent Effective Rainfall			Apparent Abstraction		
			Quasi-linear Model	Fitted	Linear Model	Quasi-linear Model	Fitted	Linear Model
in hours	in/hr	in/hr	in/hr			in/hr		
1	2	3	4	5	6	7	8	9
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.0	0.1900	0.0040	0.0839	0.0839	0.1264	0.1061	0.1061	0.0636
2.0	0.1300	0.0110	0.0815	0.0815	0.1102	0.0485	0.0485	0.0200
3.0	0.0	0.0225	0.0184	0.0184	-0.0134	-0.0184	-0.0184	0.0134
4.0	0.0	0.0280	0.0031	0.0031	-0.0278	-0.0031	-0.0031	0.0278
5.0	0.0	0.0280	-0.0427	0.0	-0.0900	0.0427	0.0	0.0900
6.0	0.0	0.0200	0.0136	0.0	0.0285	-0.0136	0.0	-0.0285
7.0	0.0	0.01500	0.0167	0.0	0.0297	-0.0167	0.0	-0.0297
8.0	0.0	0.01250	0.0042	0.0	0.0044	-0.0042	0.0	-0.0044
9.0	0.0	0.0102	0.0061	0.0	0.0089	-0.0061	0.0	-0.0089
10.0	0.0	0.0085	0.0034	0.0	0.0039	-0.0034	0.0	-0.0039
11.0	0.0	0.0070	0.0027	0.0	0.0033	-0.0027	0.0	-0.0033
12.0	0.0	0.0057	0.0013	0.0	0.0014	-0.0013	0.0	-0.0014
13.0	0.0	0.0045	0.0013	0.0	0.0021	-0.0013	0.0	-0.0021
14.0	0.0	0.0035	-0.0006	0.0	-0.0010	0.0006	0.0	0.0010
15.0	0.0	0.0025	0.0010	0.0	0.0024	-0,0010	0.0	-0.0024
16.0	0.0	0.0018	-0.0002	0.0	0.0001	0.0002	0.0	-0.0001
17.0	0.0	0.0012	0.0005	0.0	0.0014	-0.0005	0.0	-0.0014
18.0	0.0	0.0008	-0.0009	0.0	-0.0010	0.0009	0.0	0.0010
19.0	0.0	0.0004	-0.0013	0.0	-0.0014	0.0013	0.0	0.0014
20.0	0.0	0.0000	0.0000	0.0	0.0	0.0	0.0	0.0

TABLE 7: RAINFALL RUNOFF CHARACTERISTICS

BASIN 1 Storm 7

Time	Precipitation	Direct Surface Runoff	Apparent Effective Rainfall			Apparent Abstraction		
			Quasi-linear Model	Fitted	Linear Model	Quasi-linear Model	Fitted	Linear Model
in hours	in/hr	in/hr		in/hr			in/hr	
1	2	3	4	65	6	7	8	9
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.5	1.0400	0.0194	0.2561	0.2561	0.2961	0.7839	0.7839	0.7439
1.0	0.8600	0.0269	0.0912	0.0912	0.0990	0.7688	0.7688	0.7600
1.5	0.0100	0.0358	0.1151	0.1151	0.1245	-0.1051	-0.1051	-0.1145
2.0	0.0	0.0463	0.1267	0.0876	0.1335	-0.1267	-0.0876	-0.1335
2.5	0.0200	0.0590	0.0310	0.0702	-0.0040	-0.0110	-0.0502	0.0240
3.0	0.0	0.0729	0.0084	0.0324	-0.0237	-0.0084	-0.0324	0.0237
3.5	0.0	0.0772	-0.0670	0.0339	-0.1142	0.0670	-0.0339	0.1142
4.0	0.0	0.0732	0.0110	0.0	0.0137	-0.0110	0.0	-0.0137
4.5	0.0	0.0575	0.0136	0.0	-0.0169	-0.0136	0.0	0.0169
5.0	0.0	0.0436	0.0303	0.0	0.0481	-0.0303	0.0	-0.0481
5.5	0.0	0.0298	0.0239	0.0	0.0353	-0.0239	0.0	-0.0353
6.0	0.0	0.0215	0.0126	0.0	0.0171	-0.0126	0.0	-0.0171
6.5	0.0	0.0167	0.0060	0.0	0.0074	-0.0060	0.0	-0.0074
7.0	0.0	0.0134	0.0058	0.0	0.0074	-0.0058	0.0	-0.0074
7.5	0.0	0.0107	0.0083	0.0	0.0109	-0.0083	0.0	-0.0109
8.0	0.0	0.0086	0.0051	0.0	0.0059	-0.0051	0.0	-0.0059
8.5	0.0	0.0073	0.0011	0.0	0.0004	-0.0011	0.0	-0.0004
9.0	0.0	0.0063	0.0038	0.0	0.0046	-0.0038	0.0	-0.0046
9.5	0.0	0.0052	0.0053	0.0	0.0066	-0.0053	0.0	-0.0066
10.0	0.0	0.0044	-0.0008	0.0	-0.0021	0.0008	0.0	0.0021
10.5	0.0	0.0040	0.0057	0.0	0.0074	-0.0057	0.0	-0.0074

Continued Table 7

1	2	3	4	5	6	7	8	9
11.0	0.0	0.0033	-0.0009	0.0	-0.0021	0.0009	0.0	0.0021
11.5	0.0	0.0031	0.0016	0.0	0.0018	-0.0015	0.0	-0.0018
12.0	0.0	0.0026	0.0026	0.0	0.0033	-0.0026	0.0	-0.0033
12.5	0.0	0.0022	-0.0009	0.0	-0.0018	0.0010	0.0	0.0018
13.0	0.0	0.0020	0.0010	0.0	0.0013	-0.0010	0.0	-0.0013
13.5	0.0	0.0016	0.0000	0.0	0.0000	0.0000	0.0	0.0000
14.0	0.0	0.0013	0.0008	0.0	0.0011	-0.0010	0.0	-0.0011
14.5	0.0	0.0010	0.0021	0.0	0.0028	-0.0021	0.0	-0.0028
15.0	0.0	0.0008	-0.0002	0.0	-0.0006	0.0000	0.0	0.0006
15.5	0.0	0.0008	0.0013	0.0	0.0017	-0.0013	0.0	-0.0017
16.0	0.0	0.0007	-0.0003	0.0	-0.0075	0.0000	0.0	0.0075
16.5	0.0	0.0007	0.0012	0.0	0.0016	-0.0012	0.0	-0.0016
17.0	0.0	0.0006	0.0004	0.0	-0.0008	0.0	0.0	0.0008
17.5	0.0	0.0006	0.0000	0.0	0.0000	0.0	0.0	0.0000
18.0	0.0	0.0005	0.0000	0.0	0.0000	0.0	0.0	0.0000
18.5	0.0	0.0004	-0.0001	0.0	-0.0001	0.0	0.0	0.0001
19.0	0.0	0.0003	-0.0013	0.0	-0.0017	0.0	0.0	0.0017
19.5	0.0	0.0002	0.0000	0.0	0.0	0.0	0.0	0.0
20.0	0.0	0.0000	0.0	0.0	0.0	0.0	0.0	0.0

TABLE 8 : RAINFALL RUNOFF CHARACTERISTICS

BASIN - 2   STORM 1

Time	Precipitation	Direct Surface Runoff	Apparent Effective Rainfall		Apparent Abstraction	
			Quasi-linear	Fitted	Quasi-linear	Fitted
in hours	in/hr	in/hr	in/hr.		in/hr.	
1	2	3	4	5	6	7
0	0.0	0.0	0.0	0.0	0.0	0.0
1	0.1000	0.0000	0.0628	0.0628	0.0372	0.0372
2	0.1000	0.0002	0.0249	0.0249	0.0751	0.0751
3	0.2100	0.0008	0.0209	0.0209	0.1810	0.1810
4	0.0200	0.0012	0.0817	0.0200	-0.0617	0.0000
5	0.1300	0.0015	-0.0498	0.0200	0.1798	0.1100
6	0.0500	0.0020	-0.0376	0.0150	0.0876	0.0350
7	0.2000	0.0026	0.0205	0.0150	0.1800	0.1850
8	0.0200	0.0038	0.0436	0.0150	-0.0236	0.0050
9	0.0	0.0043	0.0375	0.0100	-0.0375	-0.0100
10	0.0	0.0044	0.0135	0.0	-0.0135	0.0
11	0.0	0.0047	0.0393	0.0	-0.0393	0.0
12	0.0	0.0052	-0.0002	0.0	0.0000	0.0
13	0.0	0.0059	0.0089	0.0	-0.0089	0.0
14	0.0	0.0066	0.0291	0.0	-0.0291	0.0
15	0.0	0.0075	-0.0567	0.0	0.0567	0.0
16	0.0	0.0082	0.0082	0.0	-0.0082	0.0
17	0.0	0.0087	-0.0506	0.0	0.0506	0.0
18	0.0	0.0094	0.0281	0.0	-0.0281	0.0
19	0.0	0.0095	-0.8853	0.0	0.0853	0.0
20	0.0	0.0095	0.0578	0.0	-0.0578	0.0
21	0.0	0.0090	-0.0229	0.0	0.0229	0.0
22	0.0	0.0087	-0.0057	0.0	0.0057	0.0
23	0.0	0.0077	0.0076	0.0	-0.0076	0.0
24	0.0	0.0072	-0.0215	0.0	0.0215	0.0
25	0.0	0.0066	0.0268	0.0	-0.0268	0.0
26	0.0	0.0060	-0.0260	0.0	0.0260	0.0
27	0.0	0.0054	0.0063	0.0	-0.0063	0.0
28	0.0	0.0048	-0.0004	0.0	0.0000	0.0
29	0.0	0.0044	0.0174	0.0	-0.0174	0.0
30	0.0	0.0038	0.0006	0.0	-0.0006	0.0
31	0.0	0.0033	0.0087	0.0	-0.0087	0.0

Contd.

Continued Table 8

1	2	3	4	5	6	7
32	0.0	0.0029	-0.0051	0.0	0.0051	0.0
33	0.0	0.0026	-0.0013	0.0	0.0013	0.0
34	0.0	0.0024	0.0043	0.0	-0.0043	0.0
35	0.0	0.0022	-0.0031	0.0	0.0031	0.0
36	0.0	0.0020	0.0093	0.0	-0.0093	0.0
37	0.0	0.0018	-0.0092	0.0	0.0092	0.0
38	0.0	0.0017	0.0045	0.0	-0.0045	0.0
39	0.0	0.0015	-0.0029	0.0	0.0029	0.0
40	0.0	0.0015	0.0013	0.0	-0.0013	0.0
41	0.0	0.0013	0.0004	0.0	0.0000	0.0
42	0.0	0.0012	-0.0018	0.0	0.0018	0.0
43	0.0	0.0011	0.0049	0.0	-0.0049	0.0
44	0.0	0.0010	-0.0048	0.0	0.0048	0.0
45	0.0	0.0009	0.0067	0.0	-0.0061	0.0
46	0.0	0.0008	0.0	0.0	0.0	0.0
47	0.0	0.0007	0.0	0.0	0.0	0.0
48	0.0	0.0007	0.0	0.0	0.0	0.0
49	0.0	0.0006	0.0	0.0	0.0	0.0

TABLE 9 : RAINFALL RUNOFF CHARACTERISTICS

BASIN 2 STORM 2

Time	Precipitation	Direct surface Runoff	Apparent Effective Rainfall: Quasi-linear Model	Apparent Effective Rainfall: Fitted	Apparent Abstraction: Quasilinear Model	Apparent Abstraction: Fitted
in hours	in/hr	in/hr	in/hr		in/hr	
1	2	3	4	5	6	7
0	0.0	0.0	0.0	0.0	0.0	0.0
1	0.4000	0.0006	0.0510	0.0200	0.3490	0.3800
2	0.0900	0.0016	-0.0138	0.0200	0.1038	0.0700
3	0.1000	0.0026	-0.0009	0.0100	0.1009	0.0900
4	0.0700	0.0033	0.0311	0.0150	0.0399	0.0550
5	0.0000	0.0038	0.0093	0.0100	-0.0093	-0.0100
6	0.0000	0.0037	0.0035	0.0050	-0.0035	-0.0050
7	0.0000	0.0034	0.1276	0.0350	-0.1276	-0.0350
8	0.0000	0.0038	0.0972	0.0650	-0.0972	-0.0650
9	0.0000	0.0043	-0.0148	0.1100	0.0148	-0.1100
10	0.0000	0.0048	0.1006	0.1000	-0.1006	-0.1000
11	0.0000	0.0081	-0.0562	0.0900	0.0562	-0.0900
12	0.5100	0.0134	0.0546	0.0900	0.4554	0.4200
13	0.2000	0.0173	0.1059	0.0850	0.0941	0.1750
14	0.2000	0.0221	0.0068	0.0950	0.1932	0.1050
15	0.2900	0.0242	0.3285	0.0800	-0.0385	0.2100
16	0.0100	0.0260	0.0412	0.0600	-0.0312	-0.0500
17	0.0	0.0294	0.0445	0.0300	-0.0445	-0.0300
18	0.0	0.0318	-0.0778	0.0	0.0778	0.0
19	0.0	0.0406	-0.0482	0.0	-0.0482	0.0
20	0.0	0.0488	-0.0343	0.0	0.0343	0.0
21	0.0	0.0552	-0.0091	0.0	0.0091	0.0
22	0.0	0.0566	-0.0544	0.0	0.0544	0.0

Continued Table 9

1	2	3	4	5	6	7
23	0.0	0.0566	0.0491	0.0	-0.0491	0.0
24	0.0	0.0542	-0.0122	0.0	0.0122	
25	0.0	0.0503	0.0316	0.0	-0.0316	0.0
26	0.0	0.0444	-0.0123	0.0	0.0123	0.0
27	0.0	0.0395	0.0324	0.0	-0.0324	0.0
28	0.0	0.0346	-0.0510	0.0	0.0510	0.0
29	0.0	0.0307	0.0341	0.0	-0.0341	0.0
30	0.0	0.0268	0.0029	0.0	-0.0029	0.0
31	0.0	0.0239	-0.0120	0.0	0.0120	0.0
32	0.0	0.0199	-0.0080	0.0	0.0080	
33	0.0	0.0170	0.0400	0.0	-0.0400	0.0
34	0.0	0.0146	-0.0328	0.0	0.0328	0.0
35	0.0	0.0121	0.0408	0.0	-0.0408	0.0
36	0.0	0.0097	-0.0201	0.0	0.0201	0.0
37	0.0	0.0085	0.0203	0.0	-0.0203	0.0
38	0.0	0.0068	-0.0152	0.0	0.0152	0.0
39	0.0	0.0062	0.0080	0.0	-0.0080	0.0
40	0.0	0.0053	-0.0007	0.0	0.0010	0.0
41	0.0	0.0049	0.0100	0.0	-0.0100	0.0
42	0.0	0.0042	-0.0090	0.0	0.0090	0.0
43	0.0	0.0037	0.0002	0.0	-0.0002	0.0
44	0.0	0.0033	0.0154	0.0	-0.0154	0.0
45	0.0	0.0030	-0.0054	0.0	0.0054	0.0
46	0.0	0.0026	0.0	0.0	0.0	0.0
47	0.0	0.0022	0.0	0.0	0.0	0.0
48	0.0	0.0022	0.0	0.0	0.0	0.0
49	0.0	0.0021	0.0	0.0	0.0	0.0

TABLE 10 : RAINFALL RUNOFF CHARACTERISTICS

BASIN 2 STORM 3

Time	Precipi-tation	Direct surface Runoff	Apparent Effective Rainfall		Apparent Abstraction	
			Quasilinear Model	Fitted	Quasilinear Model	Fitted
in hours	in/hr	in/hr	in/hr		in/hr.	
1	2	3	4	5	6	7
0	0.0	0.0	0.0	0.0	0.0	0.0
1	0.2400	0.0013	0.2308	0.2308	0.0092	0.0092
2	0.2600	0.0042	0.1038	0.0950	0.1562	0.1650
3	0.5500	0.0054	0.0758	0.0850	0.4742	0.4650
4	0.3500	0.0122	-0.0310	0.8000	0.3810	0.2700
5	0.0700	0.0142	0.0356	0.0700	0.0344	0.0000
6	0.0300	0.0161	0.0371	0.0700	-0.0071	-0.0400
7	0.0400	0.0185	0.2277	0.0800	-0.1877	-0.0400
8	0.0300	0.0199	0.0311	0.0500	-0.0011	-0.0200
9	0.0	0.0214	0.1803	0.0	-0.1803	0.0
10	0.0	0.0229	0.0499	0.0	-0.0499	0.0
11	0.0	0.0268	-0.1016	0.0	0.1016	0.0
12	0.0	0.0302	-0.1263	0.0	0.1263	0.0
13	0.0	0.0350	-0.0789	0.0	0.0789	0.0
14	0.0	0.0394	0.0177	0.0	-0.0177	0.0
15	0.0	0.0413	0.1090	0.0	-0.1090	0.0
16	0.0	0.0408	0.0463	0.0	-0.0463	0.0
17	0.0	0.0389	0.0120	0.0	-0.0120	0.0
18	0.0	0.0369	0.2952	0.0	0.2952	0.0
19	0.0	0.0362	-0.0237	0.0	0.0237	0.0
20	0.0	0.0357	0.0094	0.0	-0.0094	0.0
21	0.0	0.0349	0.0857	0.0	-0.0857	0.0
22	0.0	0.0301	-0.0144	0.0	0.0144	0.0

Continued Table 10

1	2	3	4	5	6	7
23	0.0	0.0252	0.0207	0.0	-0.0207	0.0
24	0.0	0.0208	0.0236	0.0	-0.0236	0.0
25	0.0	0.0179	0.0790	0.0	-0.0790	0.0
26	0.0	0.0149	0.0088	0.0	-0.0088	0.0
27	0.0	0.0125	-0.0210	0.0	0.0210	0.0
28	0.0	0.0106	0.0345	0.0	-0.0345	0.0
29	0.0	0.0098	0.0028	0.0	-0.0028	0.0
30	0.0	0.0091	0.0009	0.0	-0.0009	0.0
31	0.0	0.0081	-0.0059	0.0	0.0059	0.0
32	0.0	0.0076	0.0072	0.0	-0.0072	0.0
33	0.0	0.0071	-0.0231	0.0	0.0231	0.0
34	0.0	0.0066	0.0156	0.0	-0.0156	0.0
35	0.0	0.0060	0.0046	0.0	-0.0046	0.0
36	0.0	0.0055	0.0175	0.0	-0.175	0.0
37	0.0	0.0047	0.0006	0.0	-0.0006	0.0
38	0.0	0.0042	-0.0112	0.0	0.0112	0.0
39	0.0	0.0037	0.0138	-0.0	-0.0138	0.0
40	0.0	0.0034	-0.0151	0.0	0.0151	0.0
41	0.0	0.0032	-0.0202	0.0	-0.0202	0.0
42	0.0	0.0028	-0.0061	0.0	0.0061	0.0
43	0.0	0.0025	-0.0003	0.0	0.0003	0.0
44	0.0	0.0022	0.0064	0.0	-0.0064	0.0
45	0.0	0.0020	0.0011	0.0	-0.0011	0.0
46	0.0	0.0019	0.0	0.0	0.0	0.0
47	0.0	0.0016	0.0	0.0	0.0	0.0
48.	0.0	0.0015	0.0	0.0	0.0	0.0
49	0.0	0.0014	0.0	0.0	0.0	0.0

TABLE 11 : RAINFALL RUNOFF CHARACTERISTICS

BASIN 2 STORM 4

Time	Precipitation	Direct Surface Runoff	Apparent Effective Rainfall		Apparent Abstraction	
			Quasilinear Model	Fitted	Quasilinear Model	Fitted
in hours	in/hr	in/hr	in/hr		in/hr	
1	2	3	4	5	6	7
0	0.0	0.0	0.0	0.0	0.0	0.0
1	1.4000	0.0000	0.1359	0.1359	1.2641	1.2641
2	0.2700	0.0050	0.0824	0.0824	0.1876	0.1876
3	0.0	0.0104	0.0746	0.0746	-0.0746	-0.0746
4	0.0	0.0103	0.0849	0.0849	-0.0849	-0.0849
5	0.0	0.0108	0.1206	0.1206	-0.1206	-0.1206
6	0.0	0.0127	0.0706	0.0	-0.0706	0.0
7	0.0	0.156	0.0981	0.0	-0.0981	0.0
8	0.0	0.0195	-0.0847	0.0	0.0847	0.0
9	0.0	0.0248	-0.0474	0.0	0.0474	0.0
10	0.0	0.0302	-0.0972	0.0	0.0972	0.0
11	0.0	0.0360	-0.0311	0.0	0.0311	0.0
12	0.0	0.0381	0.0203	0.0	-0.0203	0.0
13	0.0	0.0380	0.0214	0.0	-0.0214	0.0
14	0.0	0.0350	-0.0223	0.0	0.0223	0.0
15	0.0	0.0311	-0.0081	0.0	0.0081	0.0
16	0.0	0.0276	-0.0333	0.0	0.0333	0.0
17	0.0	0.0247	0.0483	0.0	-0.0483	0.0
18	0.0	0.0213	0.0129	0.0	-0.0129	0.0
19	0.0	0.0178	0.0155	0.0	-0.0155	0.0
20	0.0	0.0139	0.0182	0.0	-0.0182	0.0
21	0.0	0.0115	-0.0013	0.0	0.0013	0.0
22	0.0	0.0095	-0.0023	0.0	0.0023	0.0
23	0.0	0.0080	0.0147	0.0	-0.0147	0.0

Continued Table 11

1	2	3	4	5	6	7
24	0.0	0.0071	0.0098	0.0	-0.0098	0.0
25	0.0	0.0061	0.0108	0.0	-0.0108	0.0
26	0.0	0.0051	0.0054	0.0	-0.0054	0.0
27	0.0	0.0045	-0.0048	0.0	0.0048	0.0
28	0.0	0.0037	0.0054	0.0	-0.0054	0.0
29	0.0	0.0032	-0.0093	0.0	0.0093	0.0
30	0.0	0.0028	0.0149	0.0	-0.0149	0.0
31	0.0	0.0024	-0.0037	0.0	0.0037	0.0
32	0.0	0.0020	-0.0005	0.0	0.0005	0.0
33	0.0	0.0016	0.0034	0.0	-0.0034	0.0
34	0.0	0.0014	0.0003	0.0	-0.0003	0.0
35	0.0	0.0012	0.0017	0.0	-0.0017	0.0
36	0.0	0.0010	-0.0017	0.0	0.0017	0.0
37	0.0	0.0009	0.0015	0.0	-0.0015	0.0
38	0.0	0.0008	-0.0019	0.0	0.0019	0.0
39	0.0	0.0007	0.0036	0.0	-0.0036	0.0
40	0.0	0.0007	0.0094	0.0	-0.0094	0.0
41	0.0	0.0005	-0.0182	0.0	0.0182	0.0
42	0.0	0.0005	0.0069	0.0	-0.0069	0.0
43	0.0	0.0004	0.0026	0.0	0.0026	0.0
44	0.0	0.0006	0.0019	0.0	-0.0019	0.0
45	0.0	0.0003	-0.0009	0.0	0.0009	0.0
46	0.0	0.0003	0.0	0.0	0.0	0.0
47	0.0	0.0001	0.0	0.0	0.0	0.0
48	0.0	0.0	0.0	0.0	0.0	0.0
49	0.0	0.0	0.0	0.0	0.0	0.0

TABLE 12 RAINFALL RUNOFF CHARACTERISTICS

BASIN 2 STORM 5

Time	Precipitation	Direct Surface Runoff	Apparent Effective Rainfall: Quasilinear Model	Apparent Effective Rainfall: Fitted	Apparent Abstraction: Quasilinear Model	Apparent Abstraction: Fitted
in hours	in/hr	in/hr	in/hr		in/hr	
1	2	3	4	5	6	7
0	0.0	0.0	0.0	0.0	0.0	0.0
1	0.1900	0.0002	0.1111	0.1111	0.0789	0.0789
2	0.0400	0.0005	0.0016	0.0050	0.0384	0.0350
3	0.0200	0.0038	0.0214	0.0150	0.0000	0.0050
4	0.0800	0.0063	-0.0301	0.0200	0.1101	0.0600
5	0.3600	0.0086	0.0346	0.0200	0.3254	0.3400
6	0.3000	0.0091	0.0349	0.0300	0.2651	0.2700
7	0.3500	0.0102	0.0814	0.0400	0.2686	0.3100
8	0.1500	0.0119	0.0175	0.0450	0.1325	0.1050
9	0.0000	0.0153	0.0734	0.0734	-0.0734	-0.0734
0	0.1000	0.0179	0.0579	0.0579	0.0421	0.0421
1	0.0700	0.0216	0.0723	0.0723	-0.0023	0.0023
2	0.0	0.0255	0.0564	0.0564	-0.0564	-0.0564
3	0.0	0.0299	-0.0385	0.0	0.0385	0.0
4	0.0	0.0340	-0.0077	0.0	0.0077	0.0
5	0.0	0.0348	-0.0161	0.0	0.0161	0.0
6	0.0	0.0340	0.0058	0.0	-0.0058	0.0
7	0.0	0.0318	-0.0046	0.0	0.0046	0.0
8	0.0	0.0294	0.0024	0.0	-0.0024	0.0
9	0.0	0.0265	0.0005	0.0	-0.0005	0.0
0	0.0	0.0236	-0.0027	0.0	0.0027	0.0
1	0.0	0.0206	0.0059	0.0	0.0059	0.0
2	0.0	0.0177	-0.0083	0.0	0.0083	0.0
3	0.0	0.0148	0.0348	0.0	-0.0348	0.0

Continued Table 12

	2	3	4	5	6	7
	0.0	0.0119	−0.0012	0.0	0.0012	0.0
	0.0	0.0104	−0.0027	0.0027	0.0027	0.0
	0.0	0.0089	0.0145	0.0	−0.0145	0.0
	0.0	0.0075	0.0085	0.0	−0.0085	0.0
	0.0	0.0066	0.0016	0.0	−0.0016	0.0
	0.0	0.0060	−0.0011	0.0	0.0011	0.0
	0.0	0.0054	0.0064	0.0	−0.0064	0.0
	0.0	0.0048	0.0022	0.0	−0.0022	0.0
[illegible]	0.0	0.0044	0.0009	0.0	−0.0009	0.0
[illegible]	0.0	0.0040	0.0005	0.0	−0.0005	0.0
[illegible]	0.0	0.0036	0.0001	0.0	−0.0001	0.0
5	0.0	0.0032	0.0057	0.0	−0.0057	0.0
5	0.0	0.0028	−0.0078	0.0	0.0078	0.0
7	0.0	0.0026	0.0072	0.0	−0.0072	0.0
8	0.0	0.0021	−0.0025	0.0	0.0025	0.0
9	0.0	0.0020	0.0053	0.0	−0.0053	0.0
0	0.0	0.0017	−0.0020	0.0	0.0020	0.0
1	0.0	0.0015	−0.0005	0.0	0.0005	0.0
2	0.0	0.0014	−0.0017	0.0	0.0017	0.0
3	0.0	0.0012	0.0018	0.0	−0.0018	0.0
14	0.0	0.00 9	0.0015	0.0	−0.0015	0.0
15	0.0	0.0008	−0.0051	0.0	0.0051	0.0
46	0.0	0.0007	0.0048	0.0	−0.0048	0.0
47	0.0	0.0004	−0.0044	0.0	0.0044	0.0
48	0.0	0.0004	0.0	0.0	0.0	0.0
49	0.0	0.0002	0.0	0.0	0.0	0.0
[illegible]	0.0	0.0	0.0	0.0	0.0	0.0

TABLE 13 : RAINFALL RUNOFF CHARACTERISTICS

BASIN 2 STORM 6

Time	Precipitation	Direct Surface Runoff	Apparent Effective Rainfall		Apparent Abstraction	
			Quasilinear Model	Fitted	Quasilinear Model	Fitted
in hours	in/hr	in/hr	in/hr		in/hr	
1	2	3	4	5	6	7
0	0.0	0.0	0.0	0.0	0.0	0.0
1	0.4500	0.0002	0.0829	0.0829	0.3671	0.3671
2	0.4000	0.0028	0.0342	0.0342	0.3658	0.3658
3	0.0500	0.0048	-0.0067	0.0100	0.0567	0.0400
4	0.0	0.0061	-0.0145	0.0150	0.0145	-0.0150
5	0.0	0.0079	0.0472	0.0472	-0.0472	-0.0472
6	0.4000	0.0090	0.1015	0.1015	0.2985	0.2985
7	0.0900	0.0090	0.2750	0.2750	-0.1850	-0.1850
8	0.0600	0.0111	0.1963	0.1963	-0.1363	-0.1363
9	0.2500	0.0150	0.2953	0.1800	-0.0453	0.0700
10	0.3000	0.0257	-0.0404	0.1350	0.2600	0.1650
11	0.9000	0.0394	0.1473	0.1050	0.7527	0.7950
12	0.1000	0.0578	0.4794	0.1200	-0.3794	-0.0200
13	0.0	0.0700	0.0233	0.1350	-0.0233	-0.1350
14	0.0	0.0822	-0.1062	0.1500	0.1062	-0.1500
15	0.0	0.1036	-0.2070	0.0	0.2070	0.0
16	0.0	0.1187	-0.0677	0.0	0.0677	0.0
17	0.0	0.1245	0.0281	0.0	-0.0281	0.0
18	0.0	0.1197	-0.4300	0.0	0.4300	0.0
19	0.0	0.1104	0.3247	0.0	-0.3247	0.0
20	0.0	0.1006	0.0370	0.0	-0.0370	0.0
21	0.0	0.0772	0.0037	0.0	-0.0037	0.0
22	0.0	0.0656	0.0643	0.0	-0.0643	0.0
23	0.0	0.0553	0.0063	0.0	-0.0063	0.0

Continued Table 13

1	2	3	4	5	6	7
24	0.0	0.0456	0.0194	0.0	-0.0194	0.0
25	0.0	0.0383	0.0876	0.0	-0.0876	0.0
26	0.0	0.0315	-0.0312	0.0	0.0312	0.0
27	0.0	0.0256	0.0434	0.0	-0.0434	0.0
28	0.0	0.0227	0.0000	0.0	0.0000	0.0
29	0.0	0.0188	0.0245	0.0	-0.0245	0.0
30	0.0	0.0164	0.0145	0.0	0.0145	0.0
31	0.0	0.0139	0.0124	0.0	-0.0124	0.0
32	0.0	0.0123	0.0033	0.0	-0.0033	0.0
33	0.0	0.0110	0.0024	0.0	-0.0024	0.0
34	0.0	0.0100	0.0117	0.0	-0.0117	0.0
35	0.0	0.0090	0.0058	0.0	-0.0058	0.0
36	0.0	0.0080	-0.0007	0.0	0.0007	0.0
37	0.0	0.0074	0.0114	0.0	0.0114	0.0
38	0.0	0.0068	0.0098	0.0	-0.0098	0.0
39	0.0	0.0061	-0.0025	0.0	0.0025	0.0
40	0.0	0.0057	0.0021	0.0	-0.0021	0.0
41	0.0	0.0055	0.0123	0.0	-0.0123	0.0
42	0.0	0.0051	-0.0030	0.0	0.0030	0.0
43	0.0	0.0047	-0.0229	0.0	0.0229	0.0
44	0.0	0.0046	0.0471	0.0	-0.0471	0.0
45	0.0	0.0043	0.0	0.0	0.0	0.0
46	0.0	0.0033	0.0	0.0	0.0	0.0
47	0.0	0.0037	0.0	0.0	0.0	0.0

TABLE 14: RAINFALL RUNOFF CHARACTERISTICS

BASIN 2 STORM 7

Time	Precipitation	Direct Surface Runoff	Apparent Effective Rainfall: Quasilinear Model	Apparent Effective Rainfall: Fitted	Apparent Abstraction: Quasilinear Model	Apparent Abstraction: Fitted
in hours	in/hr	in/hr	in/hr		in/hr	
1	2	3	4	5	6	7
0	0.0	0.0	0.0	0.0	0.0	0.0
1	0.0800	0.0000	0.0111	0.0111	0.0689	0.0689
2	0.0200	0.0001	0.0018	0.0018	0.0182	0.0182
3	0.0	0.0003	0.0019	0.0019	-0.0019	-0.0019
4	0.0	0.0003	0.0044	0.0044	-0.0044	-0.0044
5	0.0	0.0004	0.0015	0.0015	-0.0015	-0.0015
6	0.5200	0.0005	0.0103	0.0103	0.5197	0.5197
7	0.0300	0.0006	0.0046	0.0046	0.0254	0.0254
8	0.0	0.0007	0.0078	0.0078	-0.0078	-0.0078
9	0.0	0.0008	0.0112	0.0112	-0.0112	-0.0112
10	0.0	0.0011	0.0080	0.0080	-0.0080	-0.0080
11	0.0	0.0014	0.2192	0.0500	-0.2192	-0.0500
12	0.0	0.0017	0.0252	0.0400	-0.0252	-0.0400
13	0.1600	0.0020	-0.0674	0.0400	0.2274	0.1200
14	0.2000	0.0024	0.0229	0.0400	0.1771	0.1600
15	0.0100	0.0064	0.0277	0.0400	-0.0177	-0.0300
16	0.0200	0.0096	0.0413	0.0300	-0.0213	-0.0100
17	0.0300	0.0109	0.0389	0.0250	-0.0089	0.0050
18	0.0	0.0121	0.0132	0.0250	-0.0132	-0.0250
19	0.3000	0.0133	0.668	0.0100	0.2332	0.2900
20	0.0	0.0146	0.0180	0.0	-0.0180	0.0
21	0.0	0.0161	0.0023	0.0	-0.0023	0.0
22	0.0	0.0172	-0.0640	0.0	0.0540	0.0

,Continued Table 14

1	2	3	4	5	6	7
23	0.0	0.0188	0.0978	0.0	-0.0978	0.0
24	0.0	0.0201	-0.0529	0.0	0.0529	0.0
25	0.0	0.0208	0.0096	0.0	0.0096	0.0
26	0.0	0.0201	-0.0238	0.0	0.0238	0.0
27	0.0	0.0209	-0.0796	0.0	0.0796	0.0
28	0.0	0.0202	0.0526	0.0	-0.0526	0.0
29	0.0	0.0193	0.0049	0.0	-0.0049	0.0
30	0.0	0.0178	-0.0116	0.0	0.0116	0.0
31	0.0	0.0151	-0.0028	0.0	0.0028	0.0
32	0.0	0.0136	-0.0081	0.0	0.0081	0.0
33	0.0	0.0124	0.0027	0.0	-0.0027	0.0
34	0.0	0.0110	-0.0142	0.0	0.0142	0.0
35	0.0	0.0098	0.0078	0.0	-0.0078	0.0
36	0.0	0.0085	-0.0009	0.0	0.0009	0.0
37	0.0	0.0074	0.0052	0.0	-0.0052	0.0
38	0.0	0.0063	0.0018	0.0	-0.0018	0.0
39	0.0	0.0054	-0.0032	0.0	0.0032	0.0
40	0.0	0.0046	-0.0097	0.0	0.0097	0.0
41	0.0	0.0040	0.0060	0.0	-0.0060	0.0
42	0.0	0.0036	-0.0029	0.0	0.0029	0.0
43	0.0	0.0031	0.0048	0.0	-0.0048	0.0
44	0.0	0.0025	0.0041	0.0	-0.0041	0.0
45	0.0	0.0021	-0.0006	0.0	0.0006	0.0
46	0.0	0.0017	0.0	0.0	0.0	0.0
47	0.0	0.0015	0.0	0.0	0.0	0.0
48	0.0	0.0014	0.0	0.0	0.0	0.0
49	0.0	0.0012	0.0	0.0	0.0	0.0

TABLE 15 : RAINFALL RUNOFF CHARACTERISTICS

BASIN 2 STORM 8

Time	Precipitation	Direct Surface Runoff	Apparent Effective Rainfall: Quasilinear Model	Apparent Effective Rainfall: Fitted	Apparent Abstraction: Quasilinear Model	Apparent Abstraction: Fitted
in hours	in/hr	in/hr	in/hr	in/hr	in/hr	in/hr
1	2	3	4	5	6	7
0	0.0	0.0	0.0	0.0	0.0	0.0
1	0.0700	0.0	0.0444	Same as Quasi-linear Model	0.0266	Same as Quasi-linear Model
2	0.0600	0.0005	0.0030		0.0570	
3	0.0400	0.0017	0.0058		0.0342	
4	0.0600	0.0023	0.0049		0.0551	
5	0.1500	0.0028	0.0035		0.1465	
6	0.2000	0.0030	0.0117		0.1883	
7	0.1000	0.0033	0.0132		0.0868	
8	0.1100	0.0035	0.0080		0.1020	
9	0.0100	0.0036	0.0112		-0.0012	
10	0.0100	0.0040	0.0090		0.0010	
11	0.0300	0.0045	0.0034		0.0266	
12	0.0100	0.0050	0.0022		0.0088	
13	0.0100	0.0055	-0.0013		0.0113	
14	0.0	0.0059	0.0		0.0	
15	0.0	0.0059	-0.0022		0.0022	
16	0.0	0.0059	0.0009		-0.0009	
17	0.0	0.0055	-0.0008		0.0008	
18	0.0	0.0051	0.0006		-0.0006	
19	0.0	0.0046	0.0001		-0.0001	
20	0.0	0.0043	0.0009		-0.0009	
21	0.0	0.0038	-0.0003		0.0003	
22	0.0	0.0035	-0.0001		0.0001	
23	0.0	0.0032	0.0005		-0.0005	
24	0.0	0.0030	0.0		0.0	

Continued Table 15

1	2	3	4	5	6	7
25	0.0	0.0027	-0.0005	Same as Quasi-linear Method	0.0005	Same as Quasi-linear Method
26	0.0	0.0025	0.0018		-0.0018	
27	0.0	0.0023	-0.0016		0.0016	
28	0.0	0.0021	0.0002		-0.0002	
29	0.0	0.0019	-0.0004		0.0004	
30	0.0	0.0018	0.0009		-0.0009	
31	0.0	0.0016	-0.0025		0.0025	
32	0.0	0.0015	0.0022		-0.0022	
33	0.0	0.0013	-0.0009		0.0009	
34	0.0	0.0012	-0.0003		0.0003	
35	0.0	0.0010	0.0007		-0.0007	
36	0.0	0.0001	0.0001		-0.0001	
37	0.0	0.0009	-0.0002		0.0002	
38	0.0	0.0008	0.0008		-0.0008	
39	0.0	0.0007	-0.0004		0.0004	
40	0.00	0.0007	-0.0		0.0	
41	0.0	0.0006	0.0003		-0.0003	
42	0.0	0.0006	-0.0004		0.0004	
43	0.0	0.0005	0.0005		-0.0005	
44	0.0	0.0005	-0.0001		0.0001	
45	0.0	0.0004	-0.0002		0.0002	
46	0.0	0.0004	0.0		0.0	
47	0.0	0.0004	0.0		0.0	
48	0.0	0.0004	0.0		0.0	
49	0.0	0.0003	0.0		0.0	

TABLE 16

BASIN-1

STORM NO.	VALUE OF g_1	VALUE OF g_2	TRANSLATION TIME (T) in hours
1	-1.642	0.7085	1.5
2*	-1.064	0.2166	0.0
3	-1.714	0.7557	1.0
4*	-.5923	-0.1676	0.0
5	-1.830	0.8696	1.0
6	-1.409	0.5254	1.0
7	-1.505	0.6010	1.0

Average Value of g_1 = - 1.623

Average Value of g_2 = 0.6922

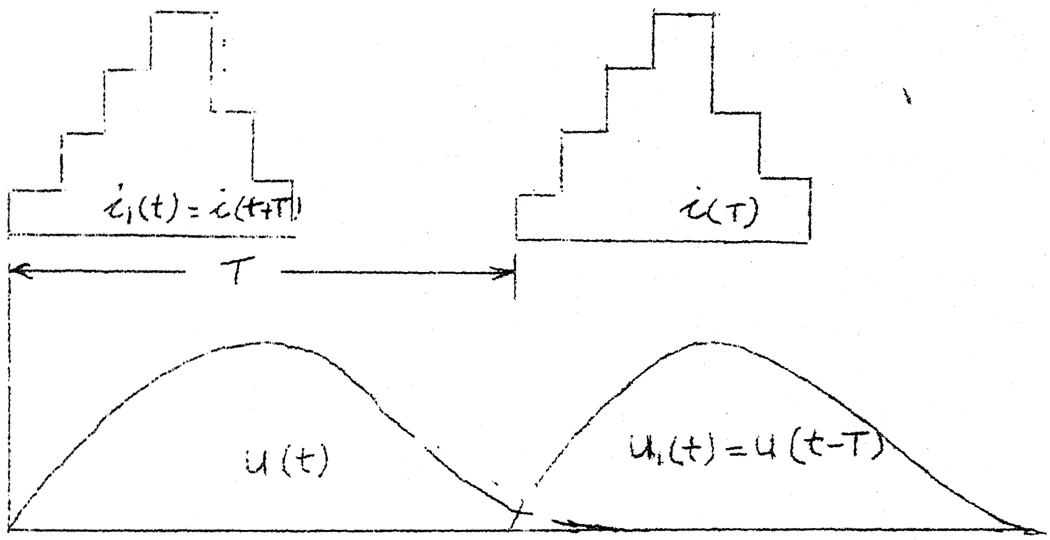
* These storms have not been taken into account for finding out the average value.

TABLE -17
BASIN - 2

STORM NO.	VALUE OF g_1	VALUE OF g_2	TRANSLATION TIME (T) in hours
1	-1.845	0.8532	4
2	-1.845	0.8627	4
3	-1.845	0.8586	4
4	-1.793	0.8158	4
5	-1.714	0.7465	3
6	-1.781	0.8098	3
7	-1.752	0.7680	4
8	-1.455	0.4958	4

APPENDIX - I

PROOF FOR THE TRANSLATION EFFECT



Considering the convolution integral 2.1,

$$Q(t) = \int_0^t u(t-\tau)\, i(\tau)\, d\tau$$

$$= \int_T^t u(t-\tau)\, i(\tau)\, d\tau$$

since $i(t) = 0$ for $0 \leqslant t \leqslant \tau$

$$= \int_T^t i_1(\tau - T)\, u_1(t-\tau+T)\, d\tau \quad \text{from identities}$$

$$= \int_0^{t-T} i_1(\tau')\, u_1(t-\tau')\, d\tau' \quad \text{where } \tau' = \tau - T$$

$$= \int_0^t i_1(\tau')\, u_1(t-\tau')\, d\tau \quad \text{since } u_1(t) = 0 \text{ for } 0 \leqslant t \leqslant T$$

$$= \int_0^t i_1(\tau)\, u_1(t-\tau)\, d\tau \quad \text{as } \tau' \text{ is a dummy variable.}$$

APPENDIX II

COMPUTER PROGRAMMES

```
$IBJOB
$IBFTC   MAIN
C           ************    INVERSE  MODEL************
      DIMENSION Q(50),G(50),A(50,50),B(50,50),C(50,50),UINV(50),U(50)
      DIMENSION X(50),TQ(50,1),D(50,50),TIN(50,1),TIP(50,1),XY(50)
      DIMENSION P(50),SUMP(50),EBS(50),SUMEBS(50),SUMX(50),SUMQ(50)
      DIMENSION SUMS(50),S(50)
 1000 CONTINUE
      READ100,NQ,NM
  100 FORMAT(4I5)
  200 READ 101,(Q(I),I=1,NQ)
  101 FORMAT(5E16.8)
      READ 102,(P(I),I=1,NM)
  102 FORMAT(16F5.2)
      NP=0
      NQM=NQ-1
   17 NP=NP+1
      PRINT 90,NP
   90 FORMAT(//,5X,*          VALUE OF NP=*,I5,/)
      M=NM+NP
      M1=M-1
      NN=NQ-M
      N=NN-1
      LIMIT=NN
      DO 1  I=1,NN
      J=I+M
      TQ(I,1)=-Q(J)
    1 A(I,1) =Q(J-1)
      M = M+1
      DO 3 J=1,NP
      M=M-1
      IF(M.LT.1)GO TO 4
      A(1,J)=Q(M)
      GO TO 3
    4 A(1,J)=0.0
    3 CONTINUE
      DO 5 J=1,NN
      DO 5 I=1,NP
      KY=I+1
      KX=J+1
```

```
    5 A(KX,KY)=A(J,I)
      CALL TRANS(A,NN,NP,B)
      CALL MULT(B,A,NP,NN,NN,NP,C)
      CALL  MULT(B,TQ,NP,NN,NN,1,TIN)
      DO 18 I=1,NP
 18   TIP(I,1)=TIN(I,1)
      CALL MATINV(C,NP,TIP,1,D)
      CALL MULT(B,C,NP,NP,NP,NP,A)
      CALL MULT(B,TIN,NP,NP,NP,1,TQ)
      DO 6 I=1,NQM
      IF(I.GT.NP)GO TO 51
      G(I) = TQ(I,1)
      GO TO 6
   51 G(I)=0.0
    6 CONTINUE
      PRINT 85
   85 FORMAT(/,5X,*VALUES OF G(I) ARE GIVEN BELOW*)
      PRINT 30,(G(I),I=1,NP)
 30   FORMAT(5X,8E15.8)
      SUBROUTINE UONE RETURNS THE VALUE OF U(1)
      CALL UONE(G,Q,U,NQ)
      PRINT 35,U(1)
   35 FORMAT(/,* U(1)=*,E20.8,/)
      UINV(1)=1.0/U(1)
      DO 7 I=2,NQ
      J=I-1
 7    UINV(I)=G(J)/U(1)
      CALL CONVOL(X,UINV,Q,NQ)
      S3=0.0
      S1=0.0
      S2=0.0
      DO 27 I=1,NM
      S3=S3+P(I)
      S1=S1+X(I)
      S2=S2+Q(I)
      SUMP(I)=S3
      SUMX(I)=S1
      SUMQ(I)=S2
      SUMEBS(I)=S3-S1
 27   SUMS(I)=S1-S2
      NM1=NM+1
      S3=SUMP(NM)
      DO 28 I=NM1,NQ
      SUMX(I)=SUMX(I-1)+X(I)
```

```
      SUMQ(I)=SUMQ(I-1)+Q(I)
      SUMEBS(I)=SA-SUMX(I)
 28   SUMS(I)=SUMX(I)-SUMQ(I)
      EBS(1)=SUMEBS(1)
      S(1)=SUMS(1)
      DO 29 I=1,NQ
      S(I)=SUMS(I)-SUMS(I-1)
 29   EBS(I)=SUMEBS(I)-SUMEBS(I-1)
      CALL TOPLIZ(UINV,U,NQ)
      PRINT 1003
 1003 FORMAT(9X,*Q(I)*,12X,*SUMQ(I)*,10X,*UINV(I)*,11X,*U(I)*,13X,*X(I)*
     1,12X,*SUMX(I)*)
      PRINT 103,(I,Q(I),SUMQ(I),UINV(I),U(I),X(I),SUMX(I),I=1,NQ)
 103  FORMAT(2X,I3,2X,E15.4,2X,E15.4,2X,E15.4,2X,E15.4,2X,E15.4,2X,E15.4
     1)
      PRINT 1004
 1004 FORMAT(9X,*P(I)*,12X,*SUMP(I)*,12X,*S(I)*,12X,*DELS(I)*,11X,*EBS(I
     1)*,8X,*SUMEBS(I)*)
      PRINT 103,(I,P(I),SUMP(I),SUMS(I),S(I),EBS(I),SUMEBS(I),I=1,NQ)
      IF(NP.EQ.LIMIT) GO TO 1000
      IF(NP.EQ.10) GO TO 1000
      IF(NP.LT.LIMIT)GO TO 17
  999 STOP
      GO TO 1000
      END
$IBFTC MULT
      SUBROUTINE MULT(A,B,NRA,NCA,NRB,NCB,C)
      DIMENSION A(50,50),B(50,50)
      DO 60 I=1,NRA
      DO 80 K=1,NCB
      SUM=0.0
      DO 70 J=1,NCA
   70 SUM=SUM+A(I,J)*B(J,K)
   80 C(I,K) = SUM
   60 CONTINUE
      RETURN
      END
$IBFTC CONVOL
      SUBROUTINE CONVOL(Y,H,X,L)
      DIMENSION H(50),X(50),Y(50)
      DO 4 I=1,L
      SUM=0.0
      DO 3 J=1,I
      KK=I-J+1
```

```
    3 SUM=SUM+H(J)*X(KK)
    4 Y(I)=SUM
      RETURN
      END
$IBFTC TOPLIZ
      SUBROUTINE TOPLIZ(U,UINV,NN)
      DIMENSION U(50),G(50),P(50),UINV(50)
      N=NN-1
      NF=N-1
      DO 10 I=1,N
      KJ=I+1
   10 P(I)=U(KJ)/U(1)
      G(1)=-U(2)/U(1)
      DO 15 I=1,NF
      SUM=0.0
      DO 20 K=1,I
      KK=I-K+1
      KL=I+1
   20 SUM=SUM+P(K)*G(KK)
   15 G(KL)=-(P(KL)+SUM)
      UINV(1)=1.0/U(1)
      DO 30 I=2,NN
      J=I-1
   30 UINV(I)=G(J)/U(1)
      RETURN
      END
$IBFTC UONE
      SUBROUTINE UONE(G,Q,U,N)
      DIMENSION G(50),Q(50),U(50),PHY(50)
      N1=N-1
      N2=N-2
      SUM1=0.0
      DO 1 I=1,N
      SUM1=SUM1+Q(I)
    1 PHY(I)=SUM1
      SUM2=0.0
      DO 2 I=1,N1
      J=N-I
    2 SUM2=SUM2+PHY(I)*G(J)
      SUM4=0.0
      DO 4 I=2,N1,2
```

```
4 SUM4=SUM4+4.0*Q(I)
  SUM5=0.0
  DO 5 I=3,N2,2
5 SUM5=SUM5+2.0*Q(I)
  VOLUM=(Q(1)+Q(N)+SUM 4+SUM 5)/3.0
  U(1)=(PHY(N)+SUM 2)/VOLUM
  RETURN
  END
$ ENTRY
```

THE PROGRAMMES FOR FINDING THE TRANSPOSE AND INVERSE OF MATRIX HAS NOT BEEN GIVEN

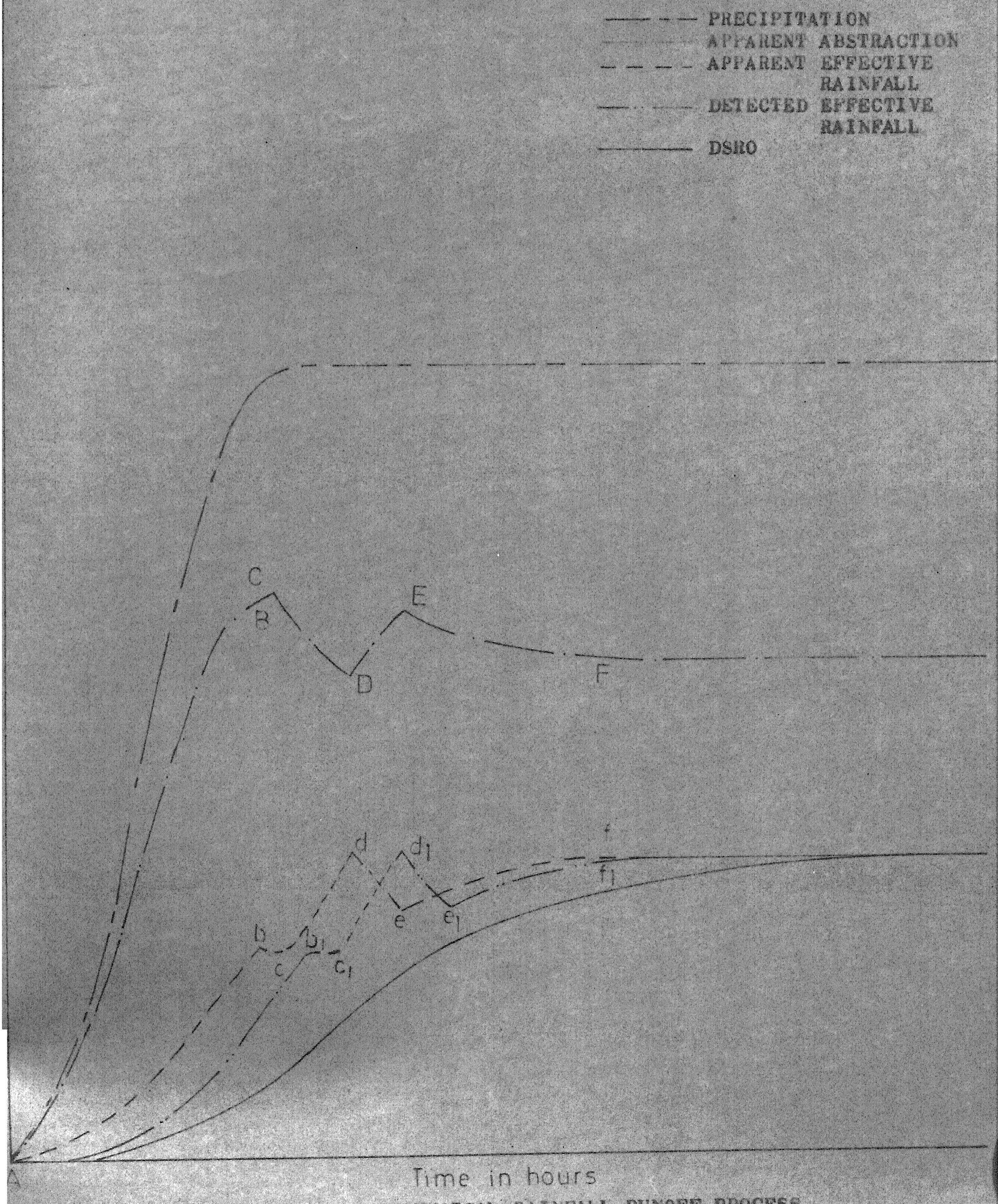


FIG. 1 THE PHYSICAL RAINFALL-RUNOFF PROCESS

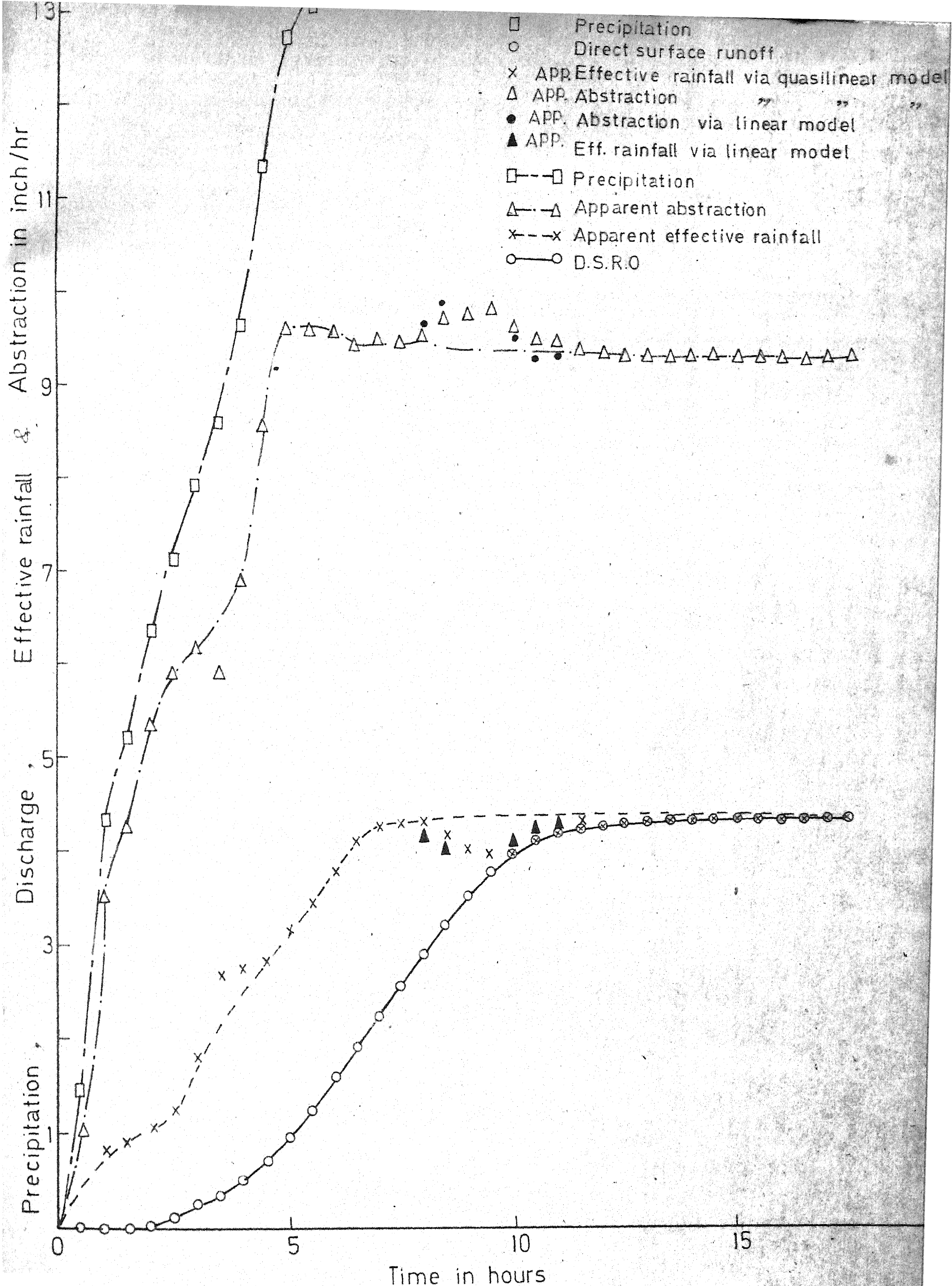


FIG. 2 CUMULATIVE RAINFALL RUNOFF CHARACTERISTICS (STORM 1- BASIN 1)

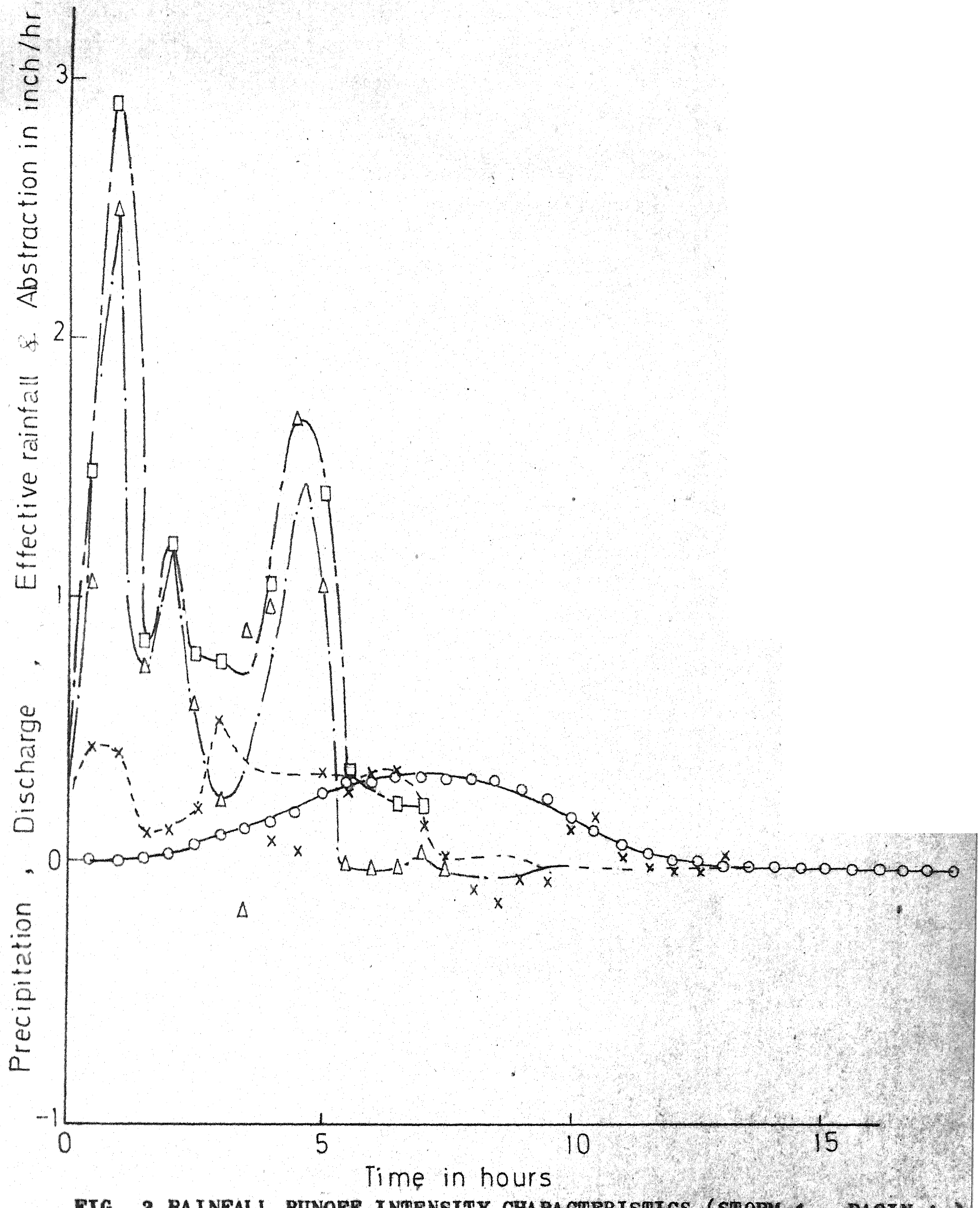


FIG. 3 RAINFALL RUNOFF INTENSITY CHARACTERISTICS (STORM 1 - BASIN 1)

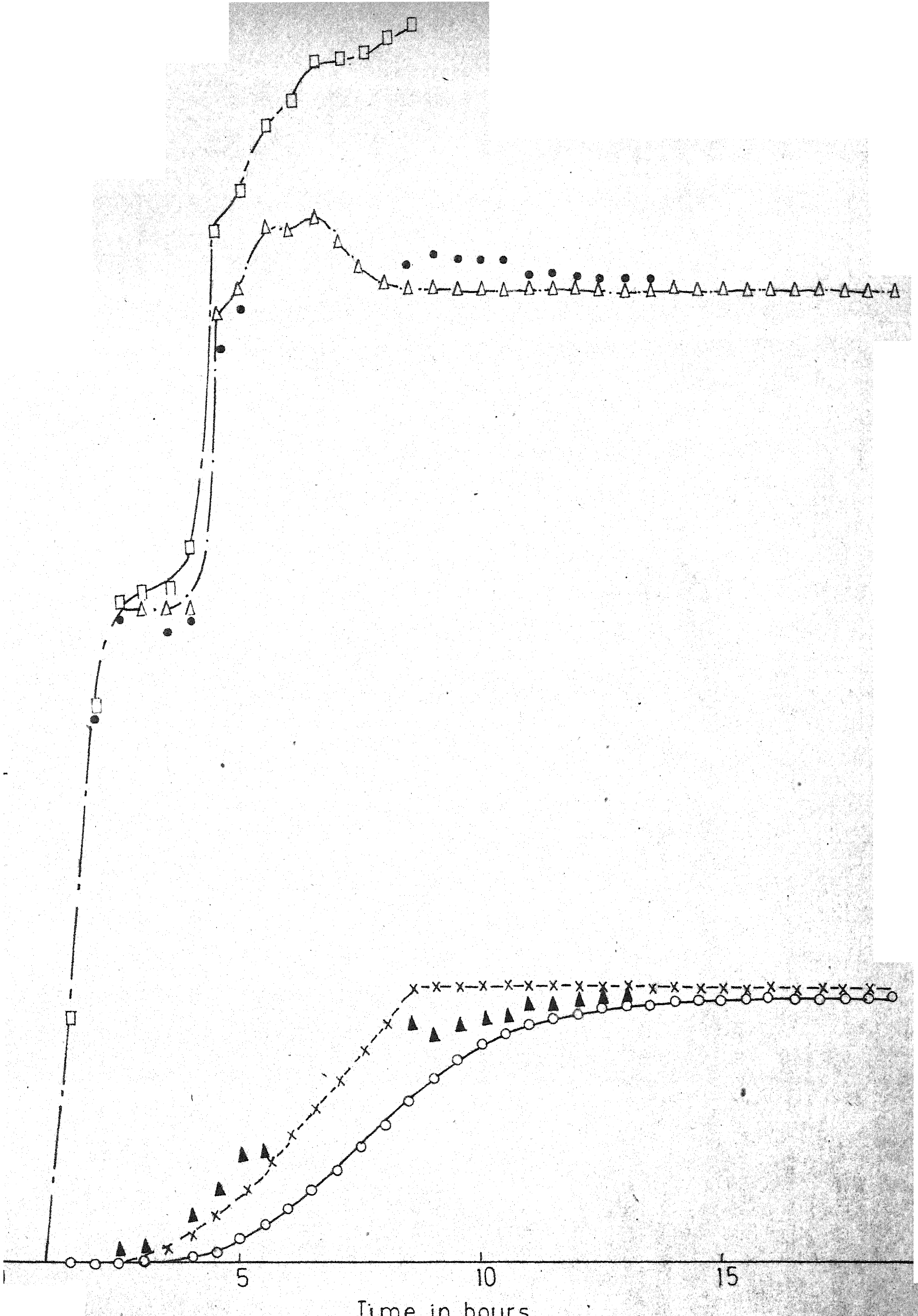


FIG. 4 CUMULATIVE RAINFALL RUNOFF CHARACTERISTICS (STORM 2- BASIN 1)

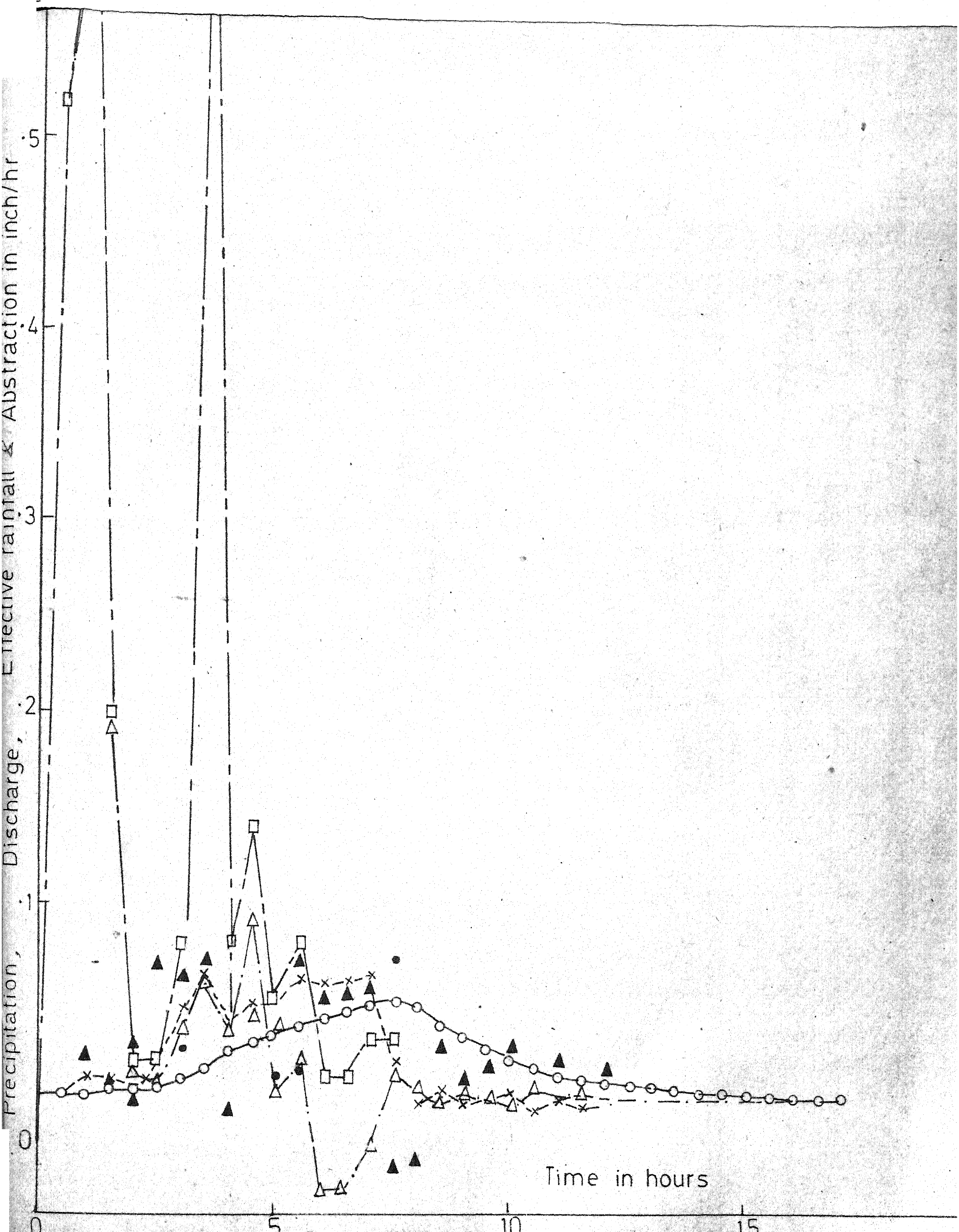


FIG. 5 RAINFALL RUNOFF INTENSITY CHARACTERISTICS (STORM 2- BASIN 1)

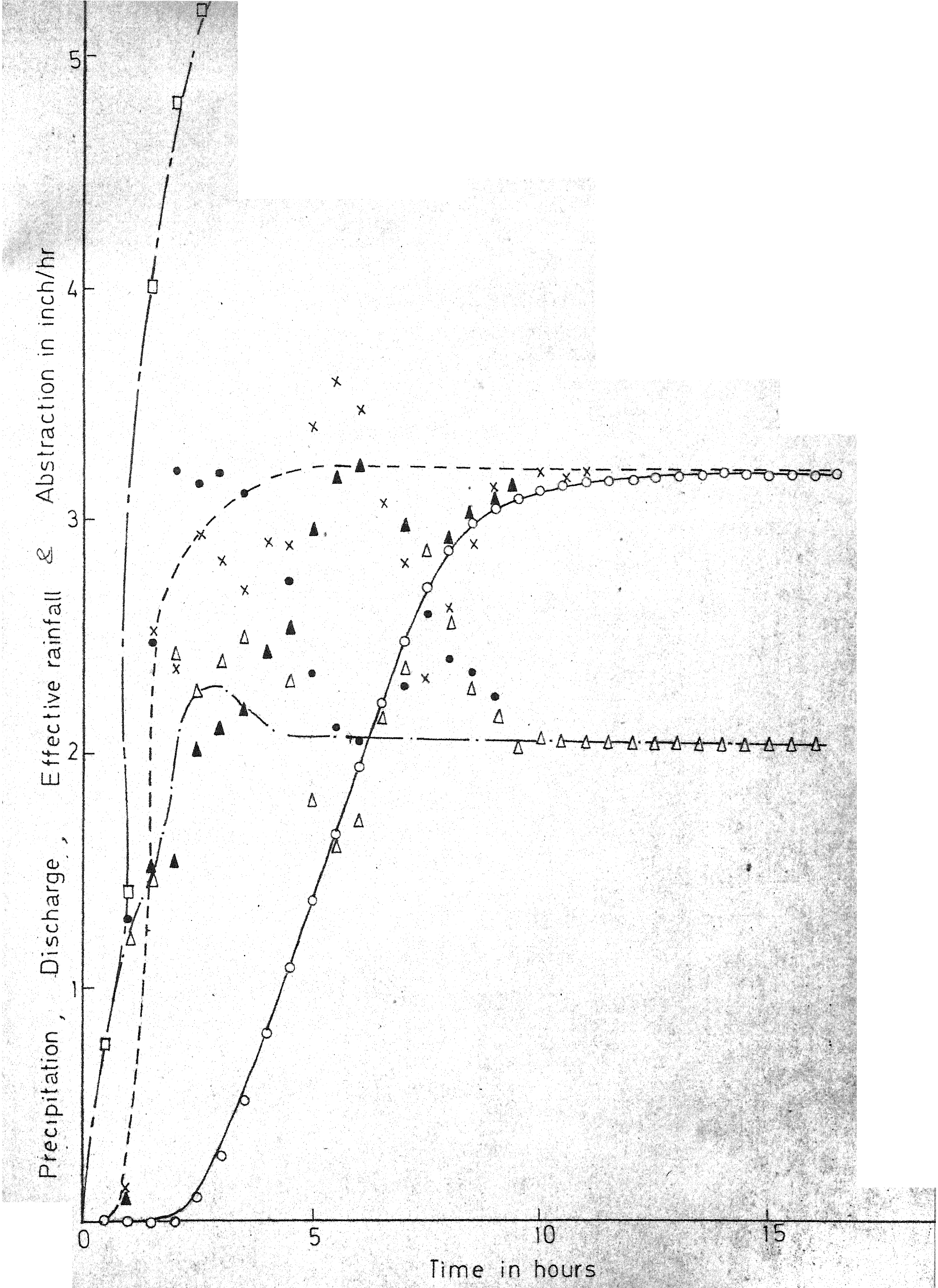


FIG. 6 CUMULATIVE RAINFALL- RUNOFF CHARACTERISTICS (STORM 3 - BASIN 1)

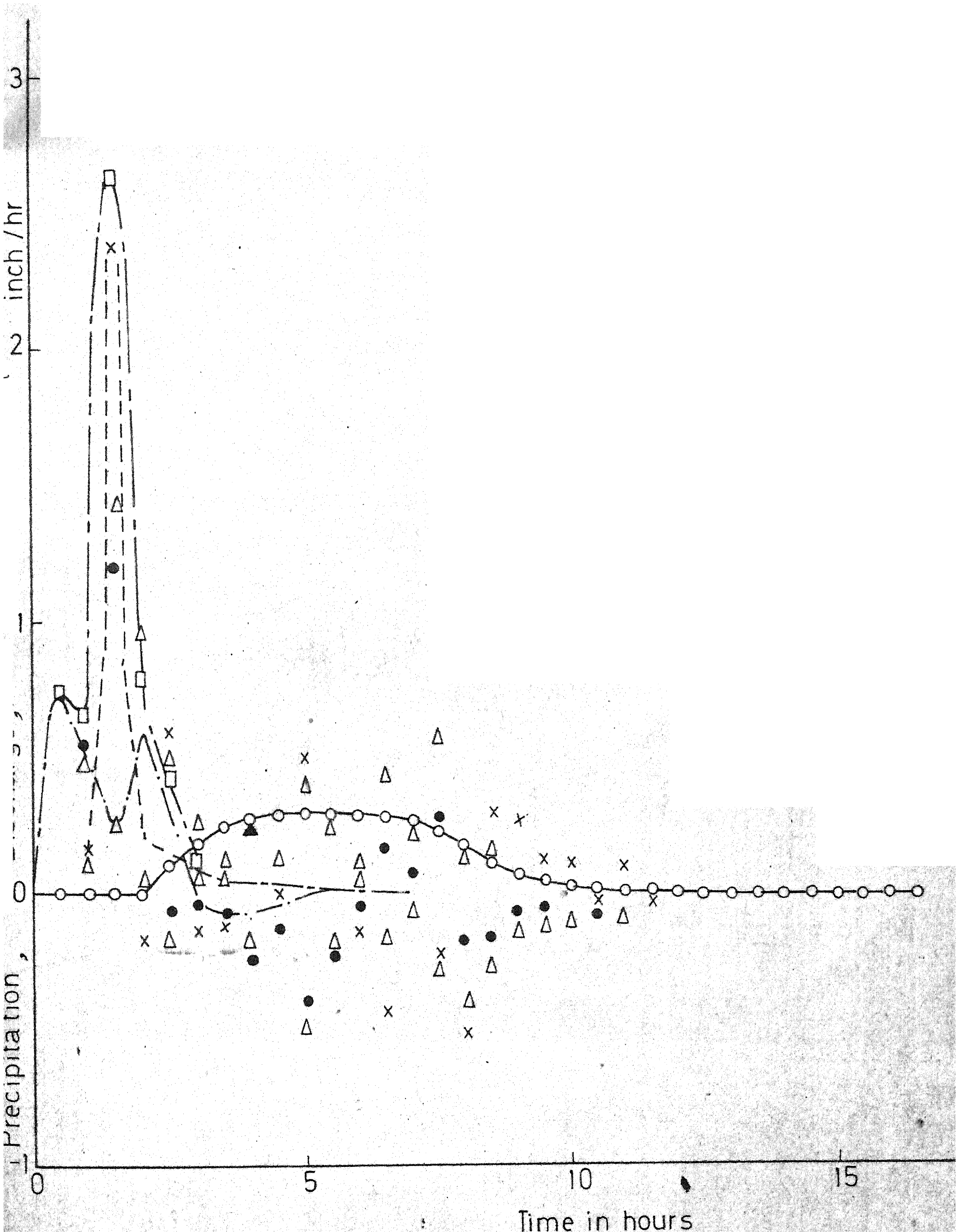


FIG. 7 RAINFALL RUNOFF INTENSITY CHARACTERISTICS (STORM 3 BASIN 1)

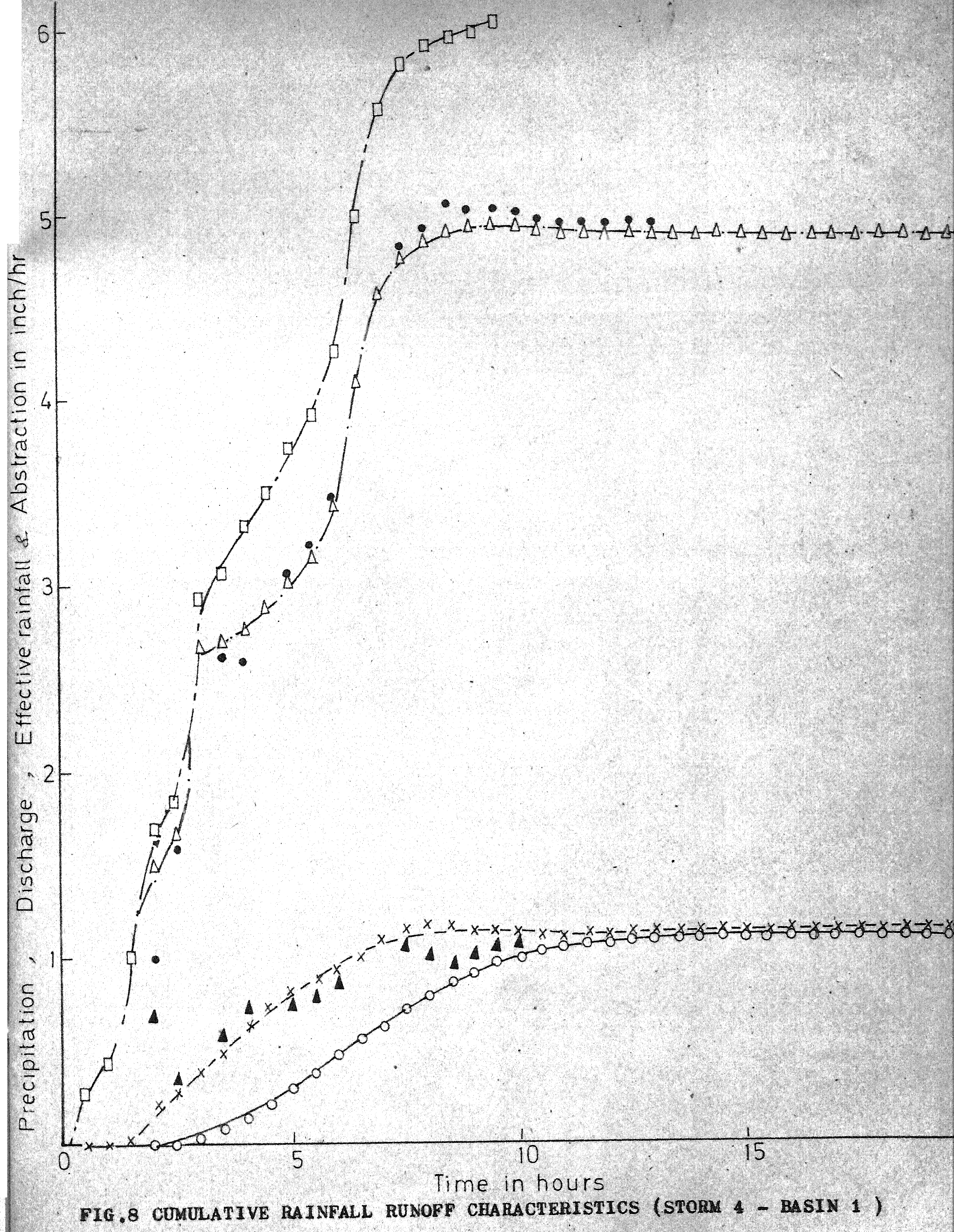


FIG.8 CUMULATIVE RAINFALL RUNOFF CHARACTERISTICS (STORM 4 - BASIN 1)

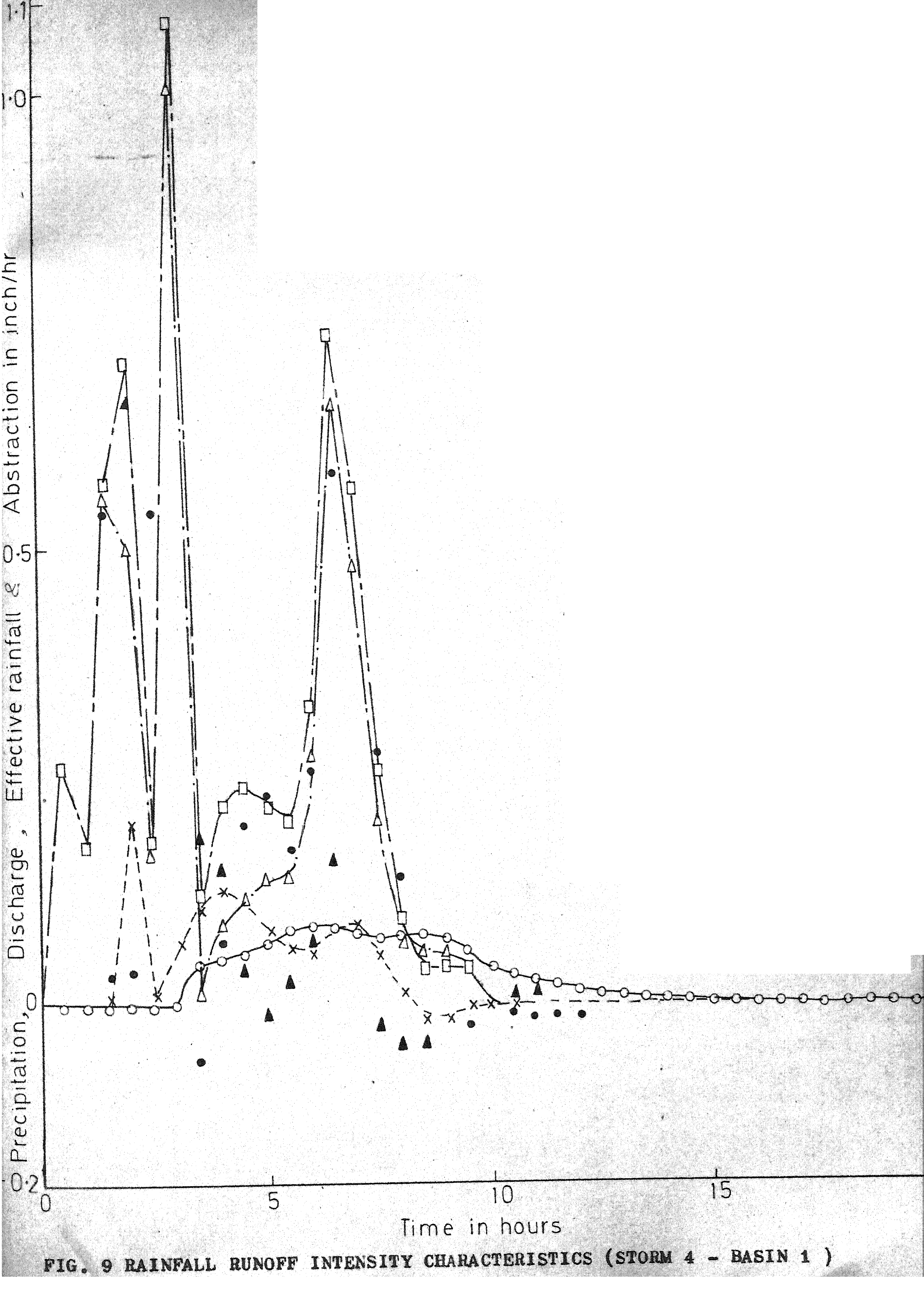


FIG. 9 RAINFALL RUNOFF INTENSITY CHARACTERISTICS (STORM 4 - BASIN 1)

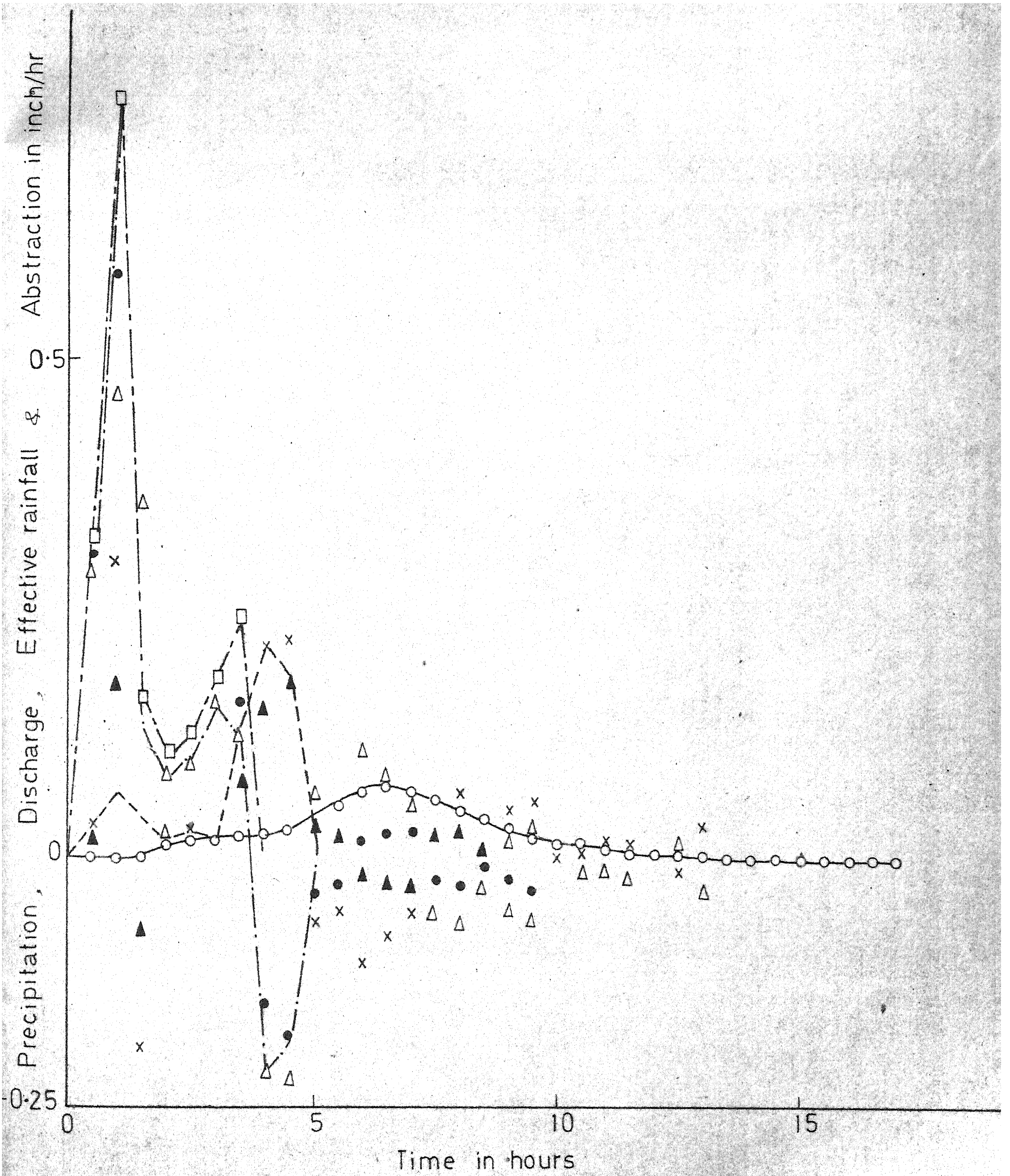


FIG. 10 RAINFALL RUNOFF INTENSITY CHARACTERISTICS (STORM 5- BASIN 1)

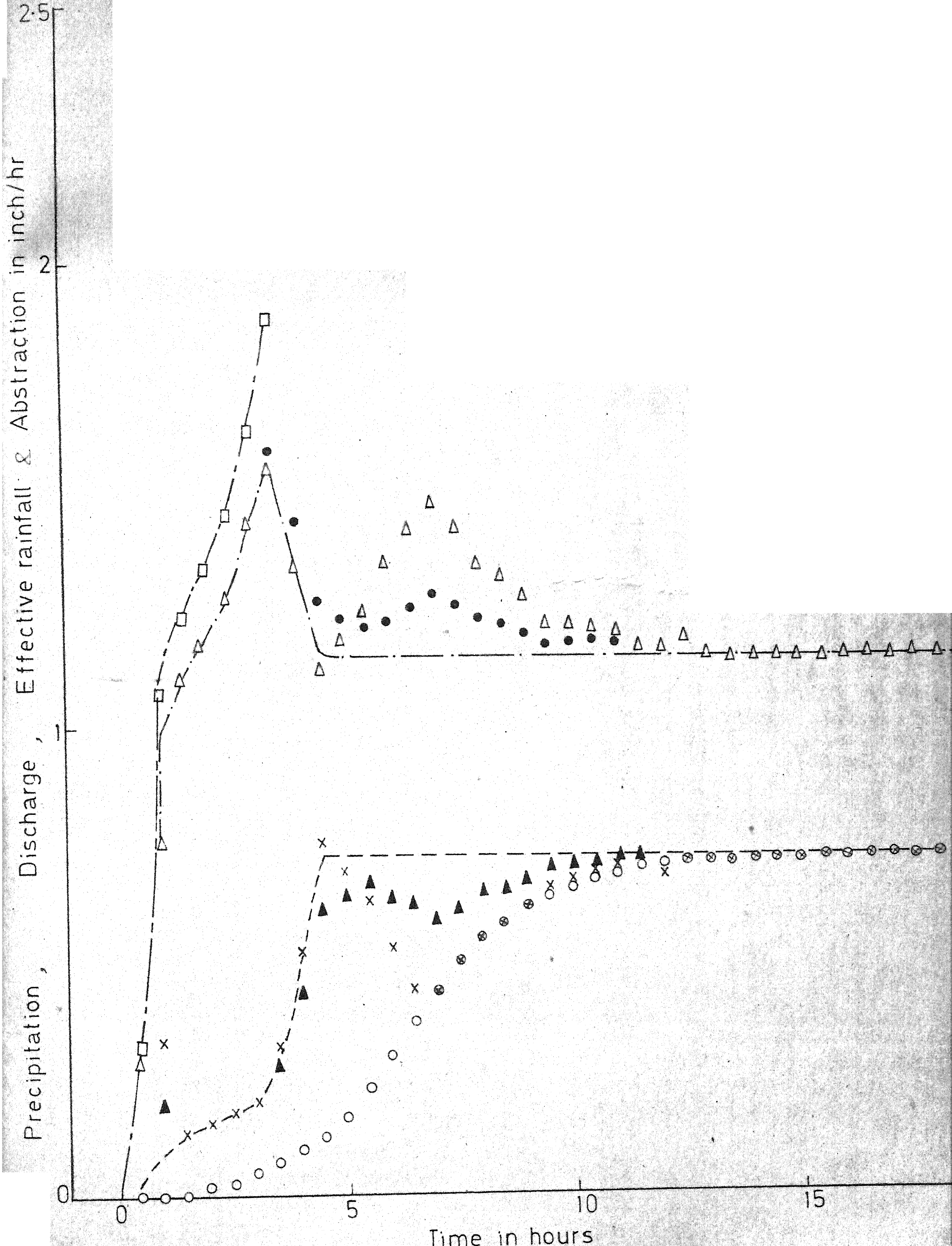


FIG. 11 : CUMULATIVE RAINFALL RUNOFF CHARACTERISTICS (STORM 5 - BASIN 1)

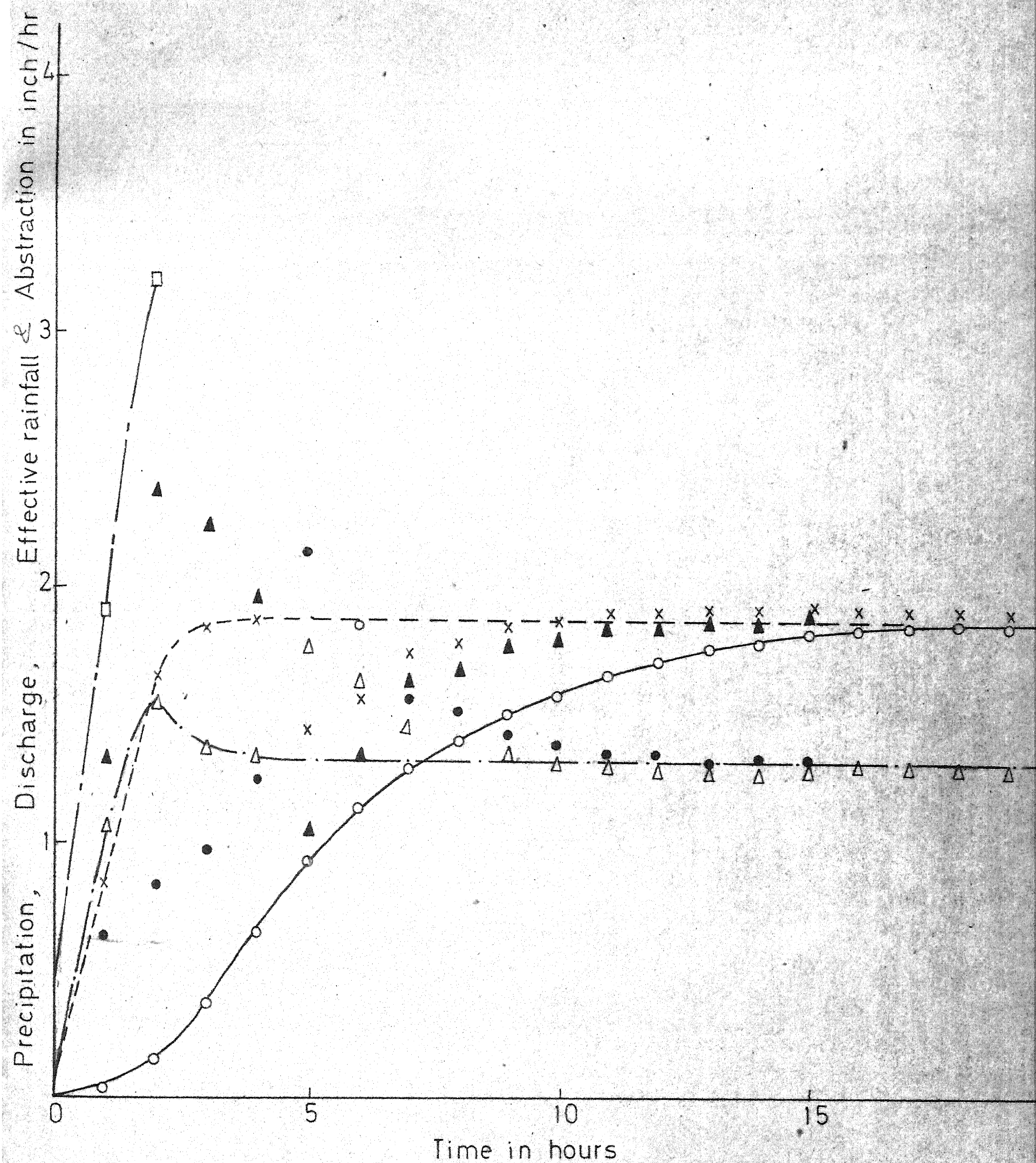


FIG. 12 CUMULATIVE RAINFALL RUNOFF CHARACTERISTICS (STORM 6- BASIN 1)

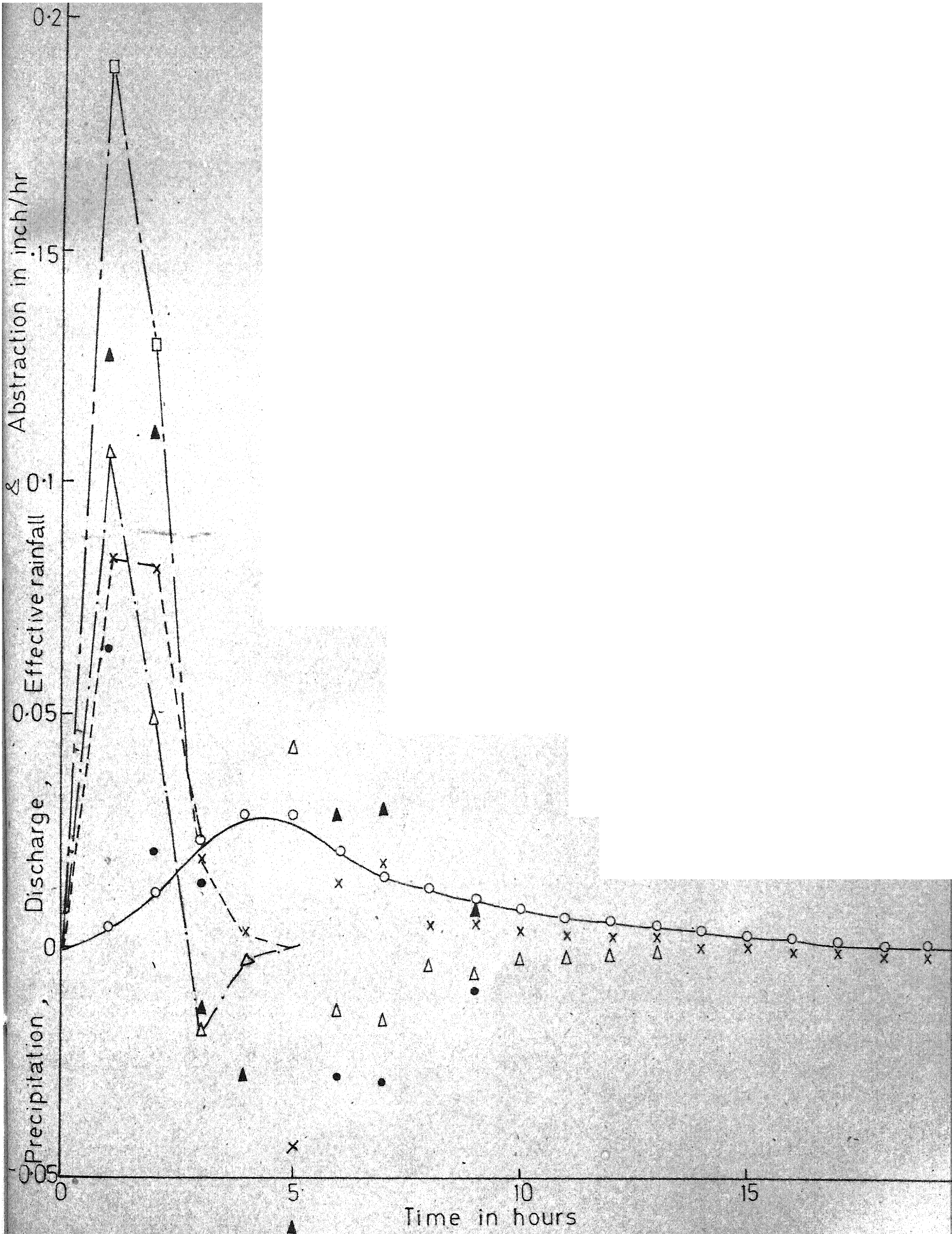


FIG. 13 RAINFALL RUNOFF INTENSITY CHARACTERISTICS (STORM 6- BASIN 1)

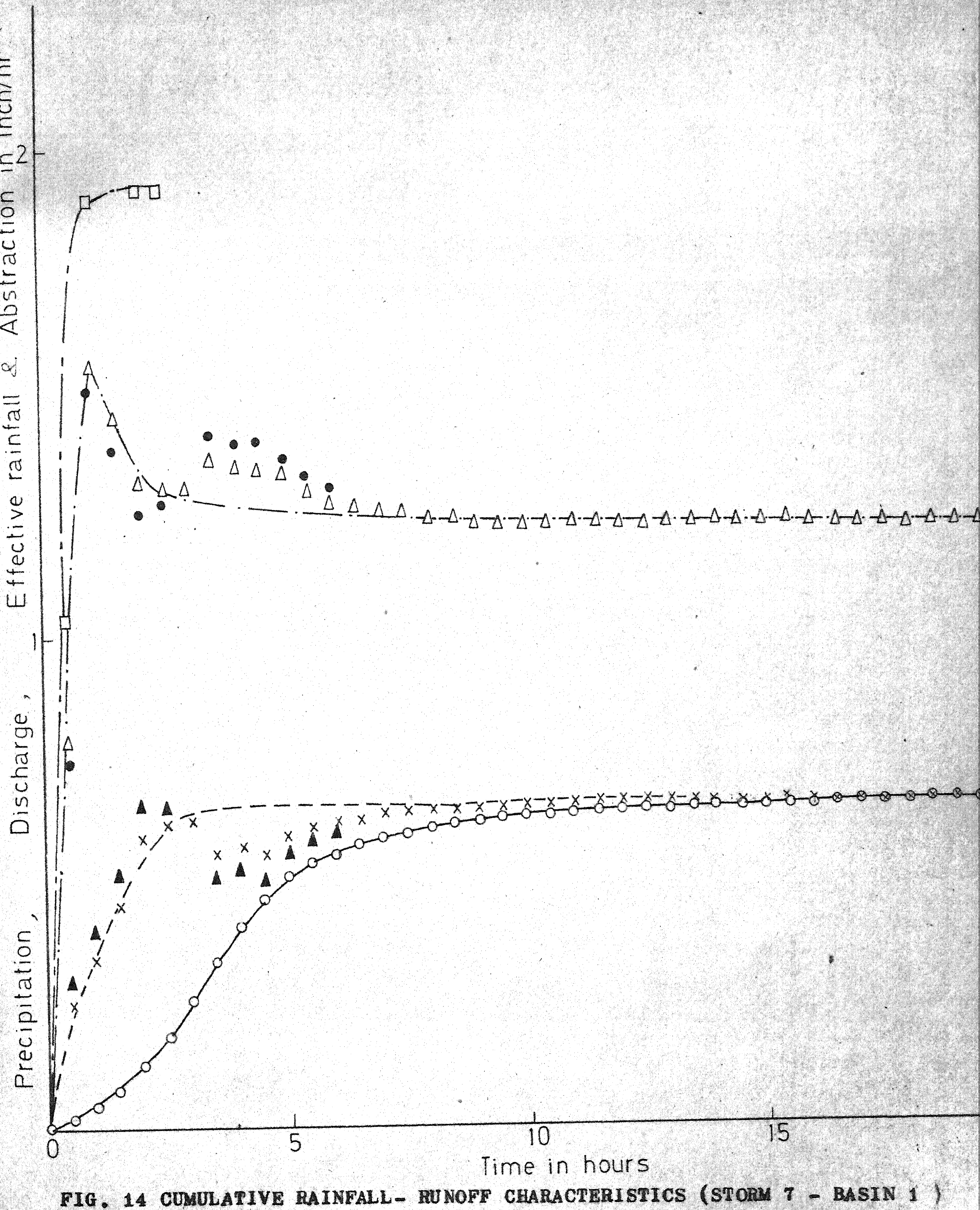


FIG. 14 CUMULATIVE RAINFALL- RUNOFF CHARACTERISTICS (STORM 7 - BASIN 1)

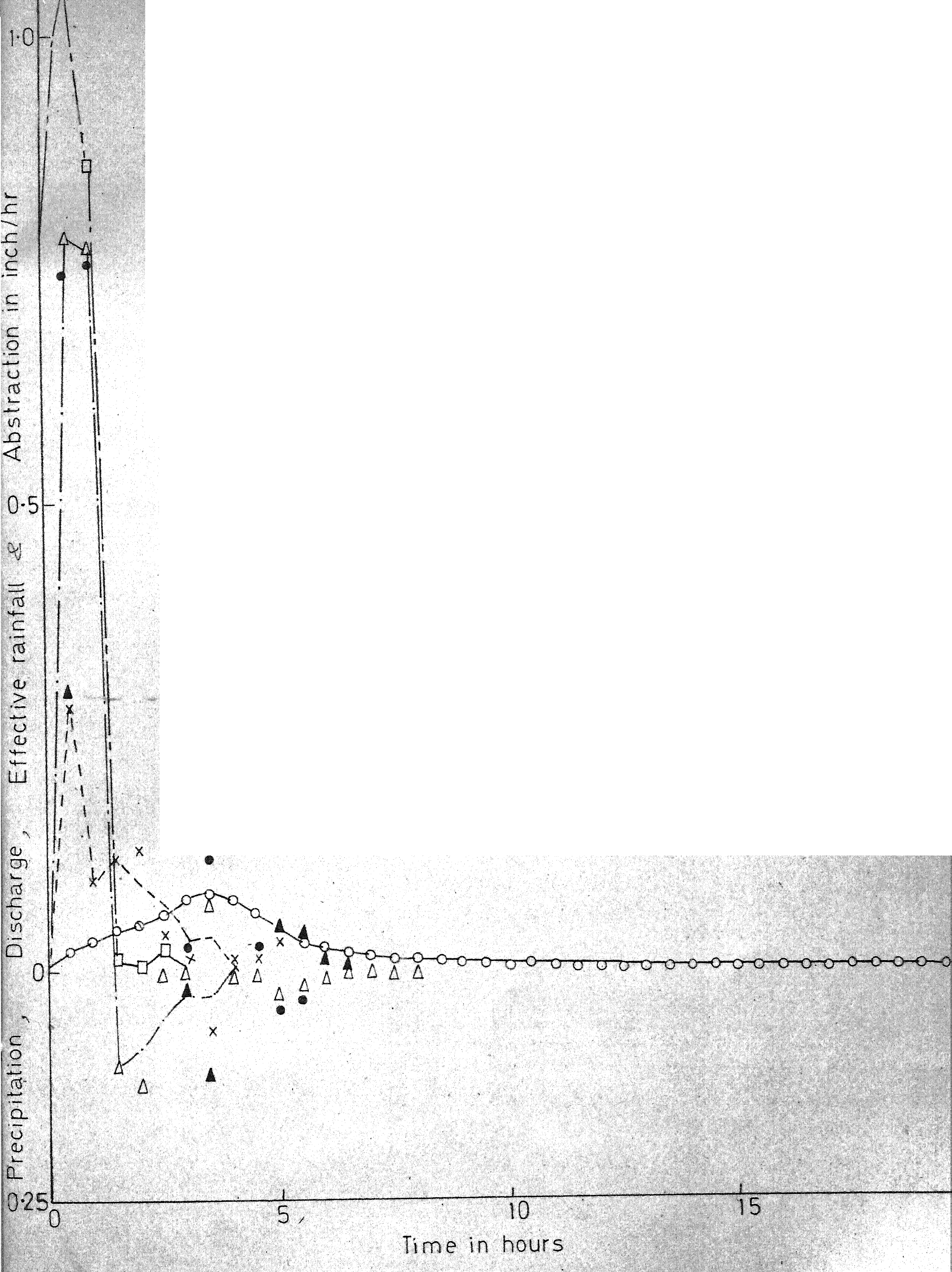


FIG. 15 RAINFALL RUNOFF INTENSITY CHARACTERISTICS (STORM 7- BASIN 1)

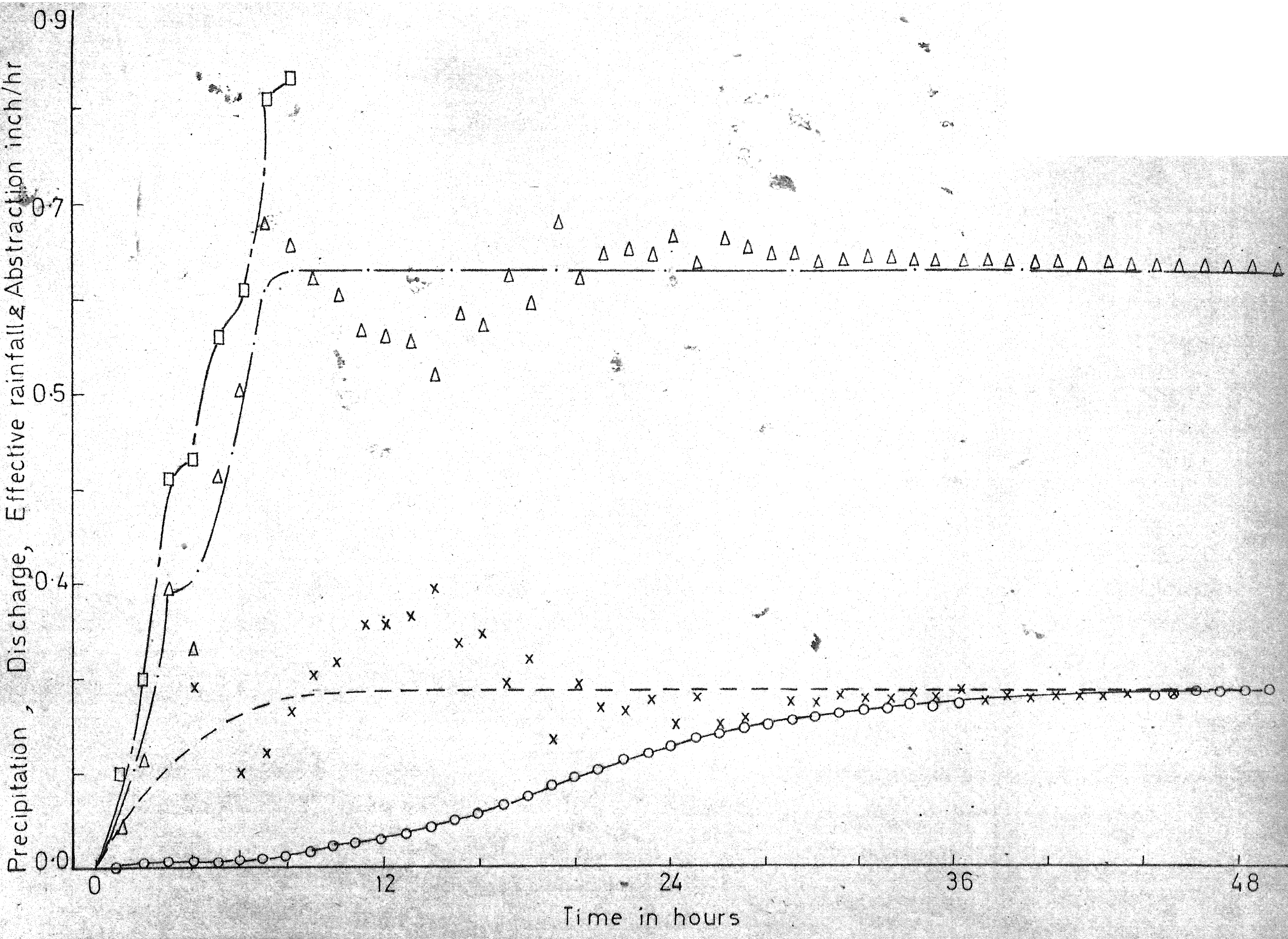


FIG. 16 CUMULATIVE RAINFALL RUNOFF CHARACTERISTICS (STORM 1 - BASIN 1)

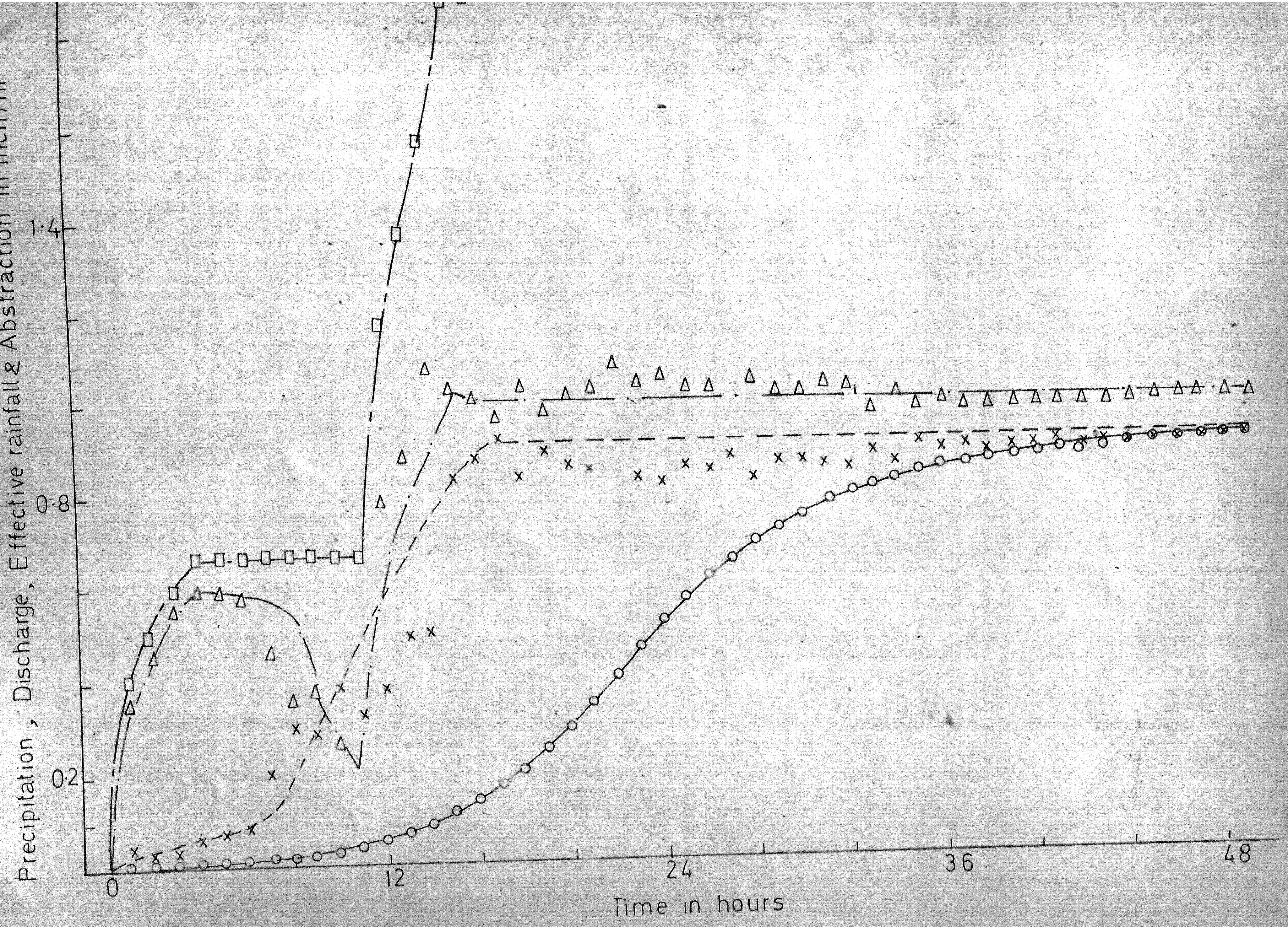


FIG. 13 CUMULATIVE RAINFALL RUNOFF CHARACTERISTICS (STORM 2 - BASIN 2)

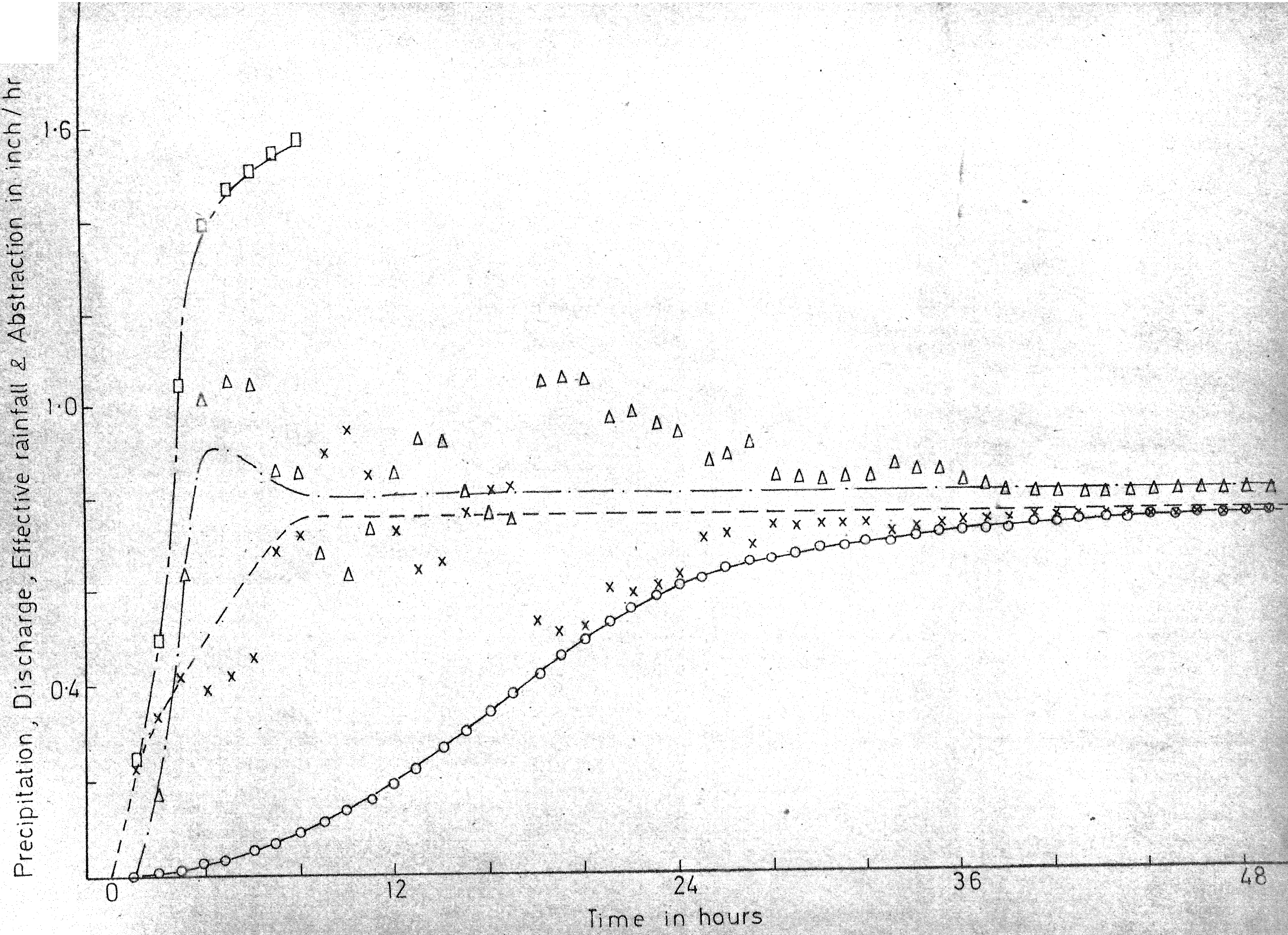


FIG. 18 CUMULATIVE RAINFALL RUNOFF CHARACTERISTICS (STORM 3 - BASIN 2)

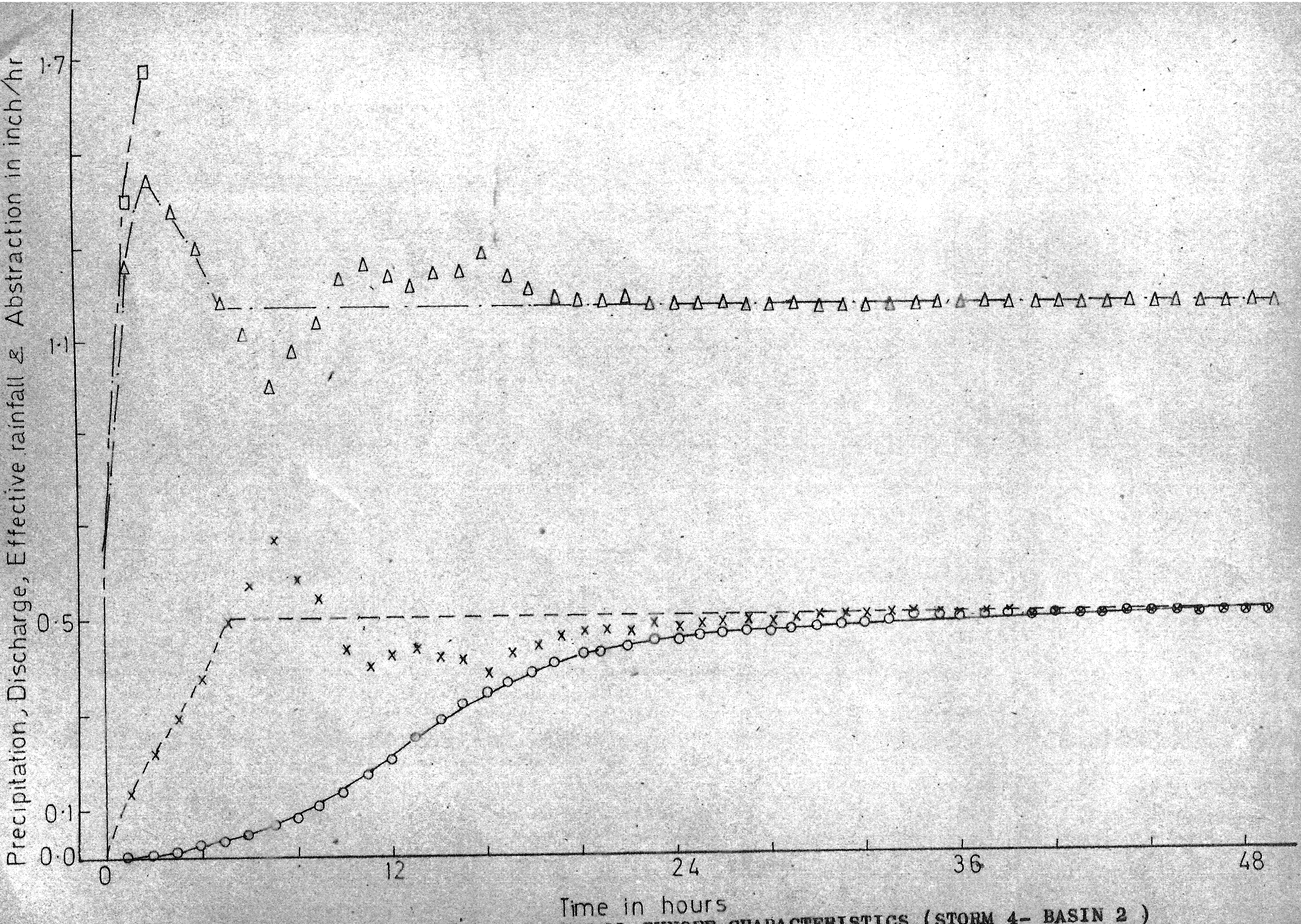


FIG 19 CUMULATIVE RAINFALL RUNOFF CHARACTERISTICS (STORM 4- BASIN 2)

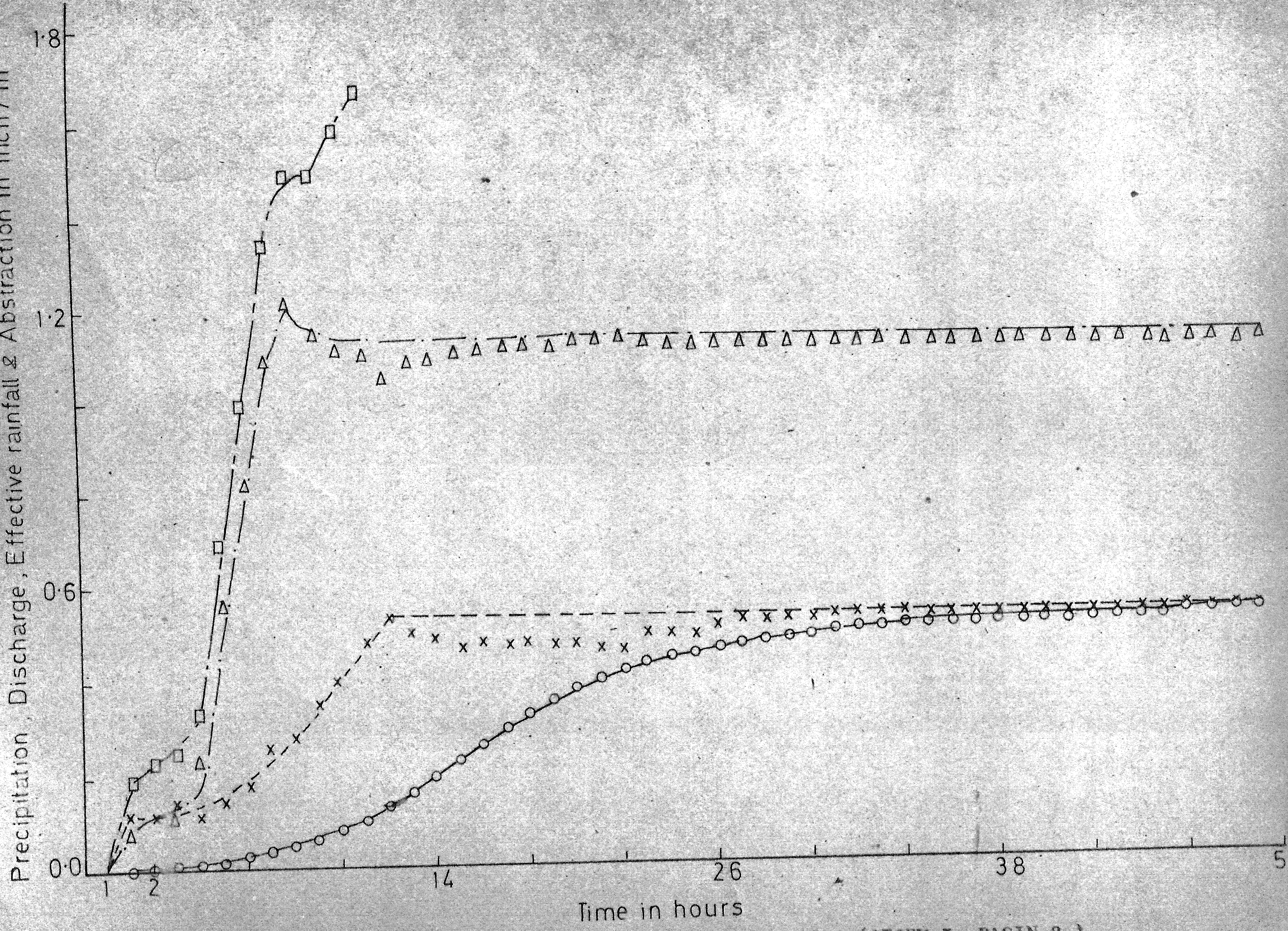
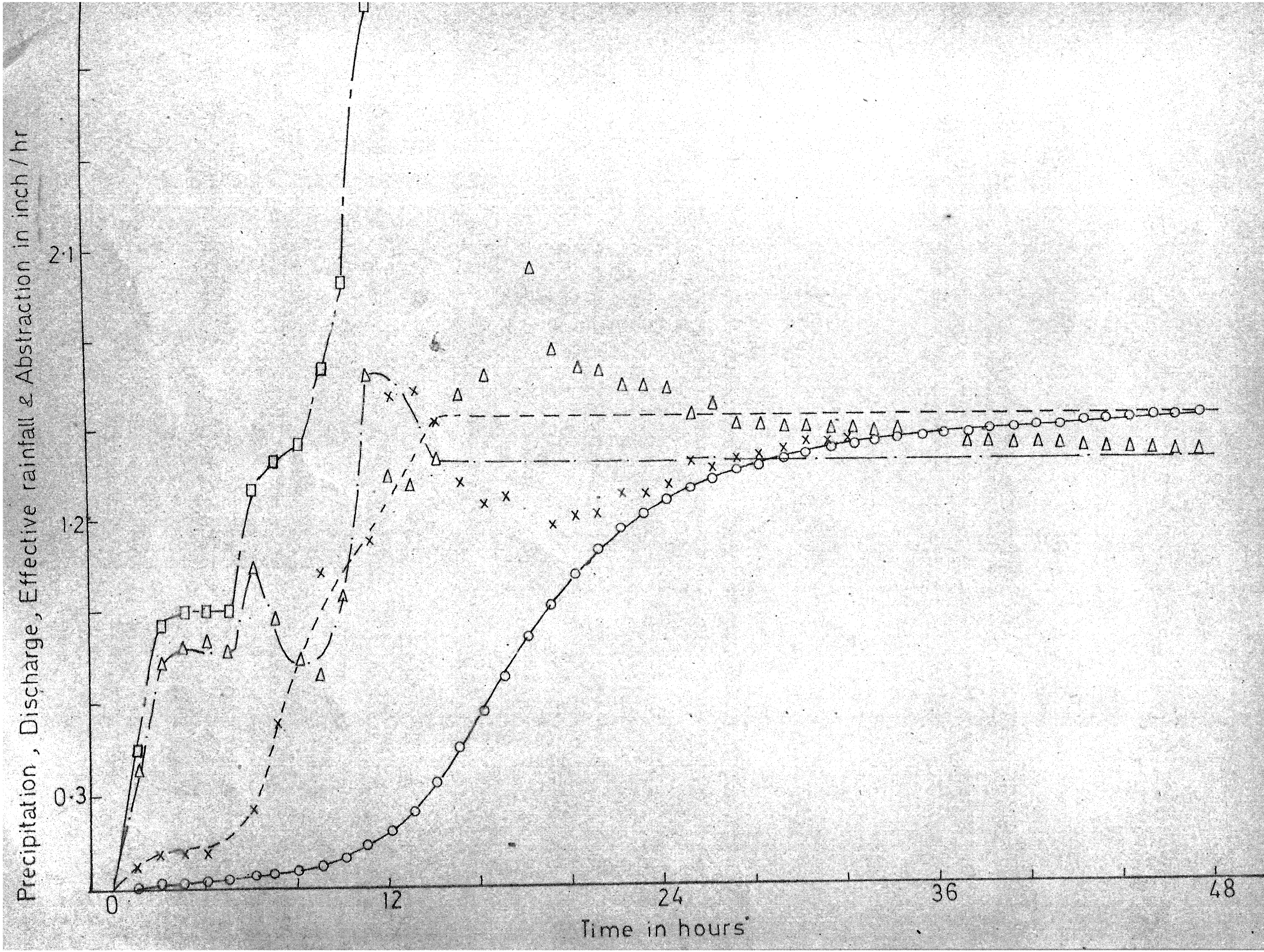


FIG. 20 CUMULATIVE RAINFALL RUNOFF CHARACTERISTICS (STORM 5- BASIN 2)



Precipitation , Discharge, Effective rainfall & Abstraction in inch / hr
2·1
1·2
0·3
0
12
24
36
48
Time in hours

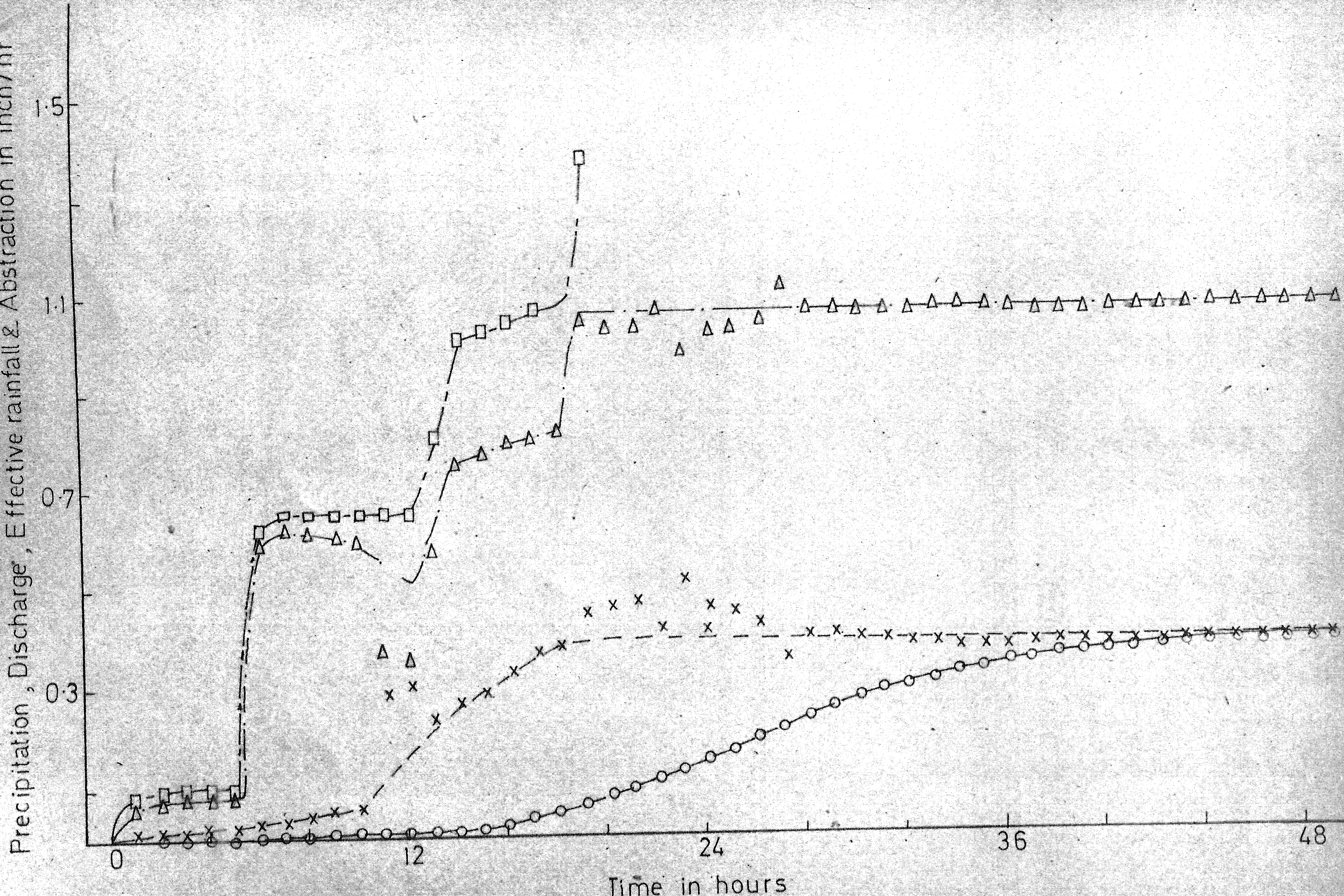


FIG. 22 CUMULATIVE RAINFALL RUNOFF CHARACTERISTICS (STORM 7- BASIN 2)

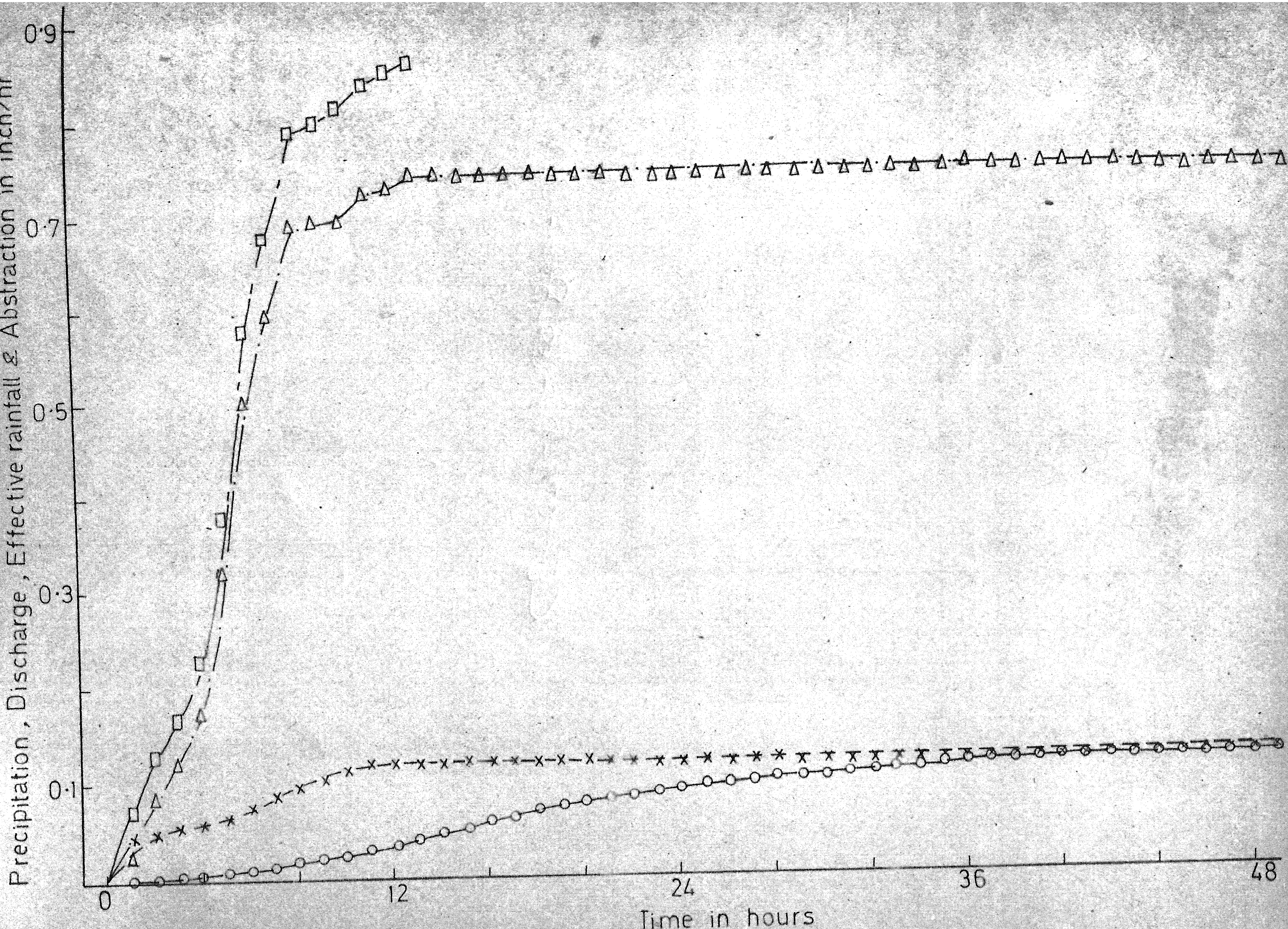


FIG. 23 CUMULATIVE RAINFALL RUNOFF CHARACTERISTICS (STORM 8 - BASIN 2)